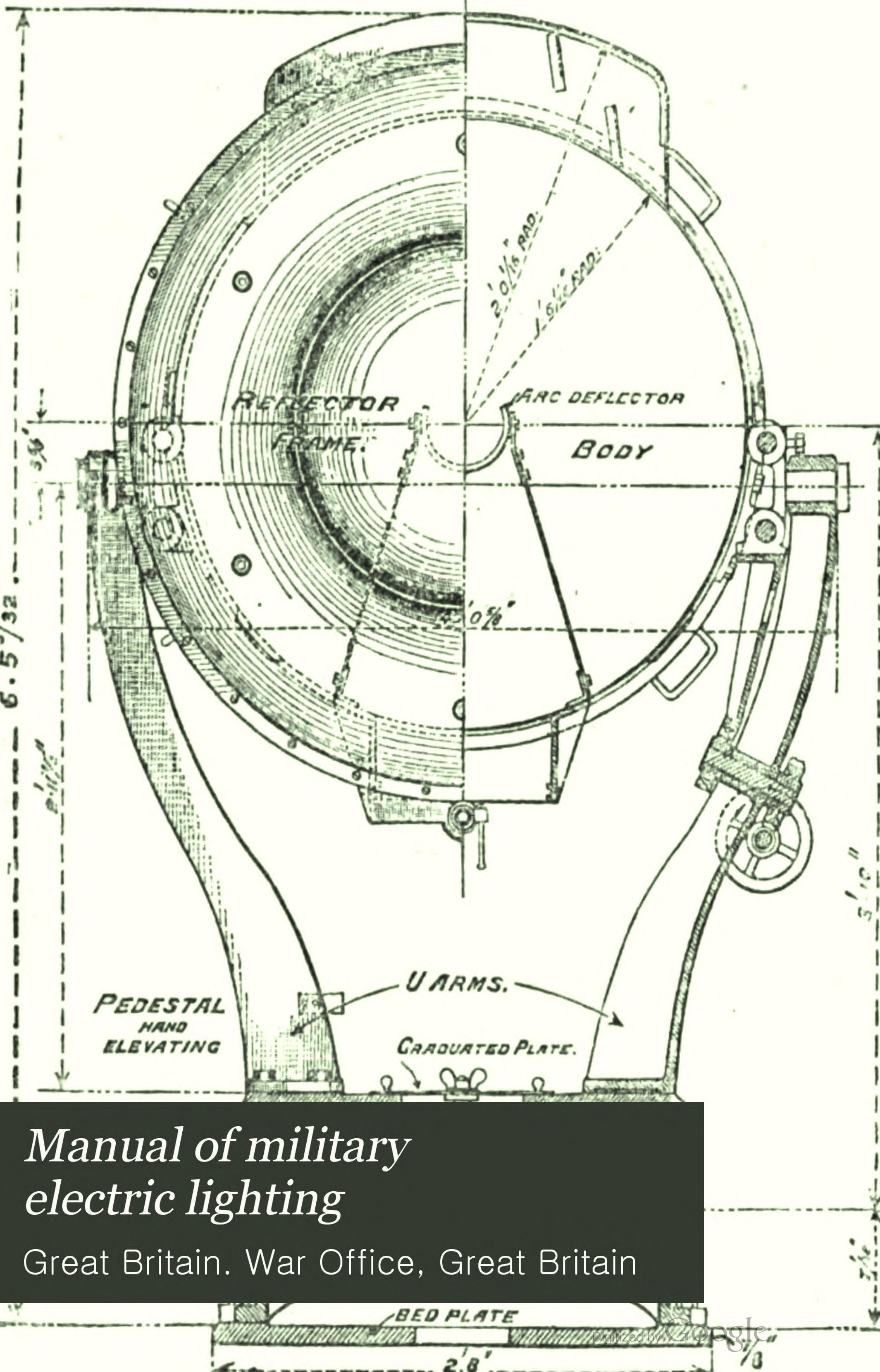

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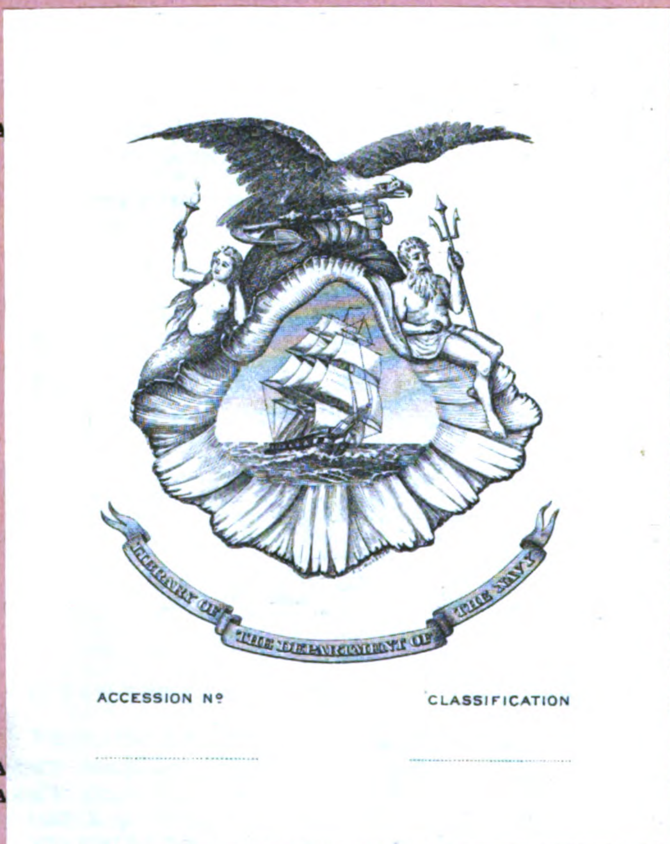

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MANUAL

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PREFACE.

THE "Manual of Electric Search Lighting" compiled at the School of Military Engineering and published by the R.E. Institute in 1890 having been out of print for some years, the present book is intended to replace it.

The branch of electric lighting specially dealt with in this volume is that known colloquially as "search lighting," and although the title of the book indicates a somewhat wider scope, those seeking fuller information on other branches of the subject should consult one or more of the recognised standard electrical works.

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LIST OF PLATES.

MANUAL

OF

MILITARY ELECTRIC LIGHTING.

CHAPTER I.

THE PRINCIPLES OF DYNAMO-ELECTRIC INDUCTION.

THE fundamental fact of dynamo electric induction is that if a conducting wire be caused to move in a magnetic field, and in so doing to cut the magnetic lines of force, there will be induced in each small portion of the length of the conducting wire a certain E.M.F. If all the E.M.F.'s thus produced in the various parts of the conducting wire be added together, due attention being paid to their direction, the resulting E.M.F. will produce a current provided that there is a path open to it, *i.e.* that the circuit is completed. Obviously this current will flow only so long as the motion is continued. If a current be produced in such a manner, work must be done in producing it, and the product,

$$\text{current} \times \text{E.M.F.} \times \text{time},$$

will be a measure of the total work done.

Now the current thus produced in the completed circuit will obviously depend for its value on the E.M.F. causing it, and this E.M.F. is dependent on three factors—

(i) The intensity of the magnetic field.
(ii) The length of the conductor cutting that field.
(iii) The relative velocity of the conductor and the magnetic field.

Or in symbols—

$$E = B\,l\,v$$

where E = E.M.F.
B = intensity of field
v = relative velocity of conductor and field
l = length of the conductor cutting the field.

(This is in C.G.S. units: to arrive at the value of the E.M.F. in volts divide by 10^8.)

Observe that it is quite immaterial which moves, *i.e.* whether the conductor moves in the field, or the field moves about the conductor, provided there be relative motion between them.

As regards the direction of current, by far the most convenient way of remembering the laws connecting direction of magnetic field or flux, motion of conductor, and resultant current is known as the right-hand rule. (*Vide* Fig. 1.)

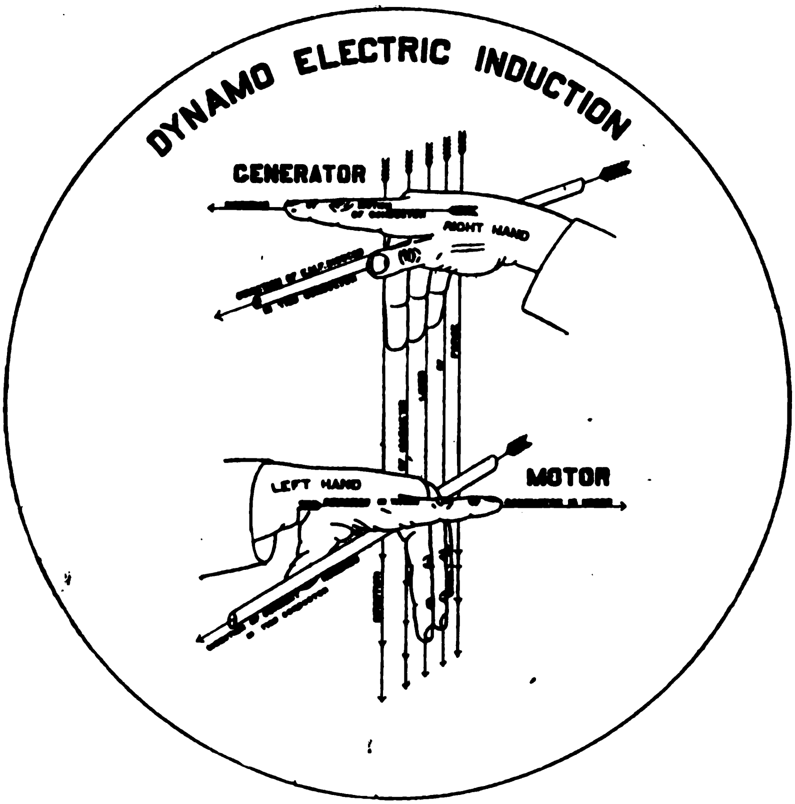

Fig. 1.

Hold the thumb, first finger, and remaining fingers of the right hand at right angles to one another (like three rectangular axes). Then if the first finger be pointed in the direction of motion, and the remaining fingers in the direction of the lines of force (*i.e.* in the direction in which a free north pole would be urged), the thumb will point in the direction of the E.M.F. produced.

The left-hand rule (for motors) will be discussed later.

If the conductor does not form a complete circuit, the electromotive force induced by its motion will not be able to cause a continuous current, but will only produce a current until the quantity of electricity conveyed thereby from one end of the conductor to the other has produced a difference of potential between the ends of the conductor equal to V, when the electromotive force produced by the motion of the conductor is balanced by that resulting from the difference of potential set up by the current, and no further

current will pass. If the motion of the conductor be suddenly arrested, the difference of potential set up by the current will then be free to act, and a current in the reverse direction will take place in the conductor until the potential of the conductor is equalised throughout.

Let us suppose, however, that the conductor forms a closed circuit.

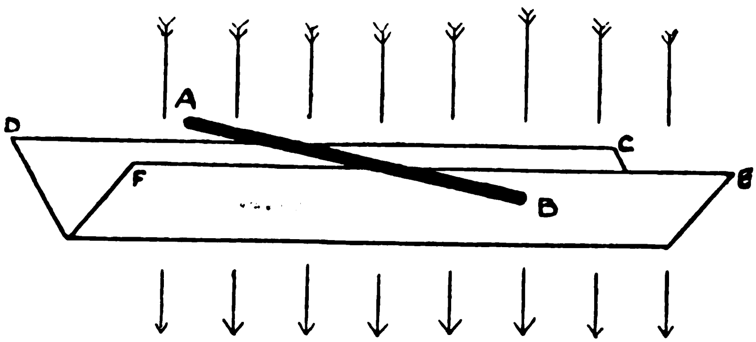

Fig. 2.

Imagine a V-shaped metallic trough, as shown in Fig. 2, and on it lying a conductor, A B, making metallic contact with the edges of the trough, and let this system stand in a magnetic field so that the lines of force flow in the direction shown by the arrows, *i.e.* a free north pole would be urged from above the trough, downwards.

If now A B be moved towards the left with a velocity v centimetres per second, there will be induced in A B an electromotive force, E, which is equal to $B l v$. This E.M.F. will urge a current from A to B (*vide* right-hand rule), which will circulate by means of the trough, and if r be the resistance of the whole path, the current will be equal to

$$\frac{B l v}{r}.$$

In order to get the maximum effect, the conductor, the direction of motion, and the lines of force must all be at right angles to one another. If they are not all perpendicular to one another, the length of the conductor, the velocity and the intensity of the magnetic field must all be resolved in directions which are at right angles to one another by multiplying the actual magnitudes by the cosines of the angles they make with such directions.*

It has been found convenient, for purposes of calculation, to represent the intensity of a magnetic field by the number of lines of force traversing a given section of the field. That is to say, a

* Or, popularly speaking, the magnitudes are diminished in the same way as a stick, for instance, appears shorter if not looked at squarely.

powerful field is represented as containing more lines of force, condensed more closely together, than a weak field. It has been conventionally arranged to represent a field of unit intensity by one line per square centimetre of section of the field.

The quantity B, therefore, is numerically equal to the number of these conventional lines of force per square centimetre. A field of intensity B will have B lines of force per square centimetre.

Now, l, the length of the conductor, is also expressed in terms of the centimetre unit, hence $l \times B$ will be the number of lines of force cut by the conductor in moving through one centimetre, and as v means the number of centimetres traversed by the conductor per second, $B\,l\,v$ will be the number of lines of force cut by the conductor per second. We now see that the electromotive force E, induced in a conductor moving across a magnetic field, is equal to the number of lines of force cut per second, and a moment's consideration will suffice to show that this is true, whether B l and v are all perpendicular to one another or not.

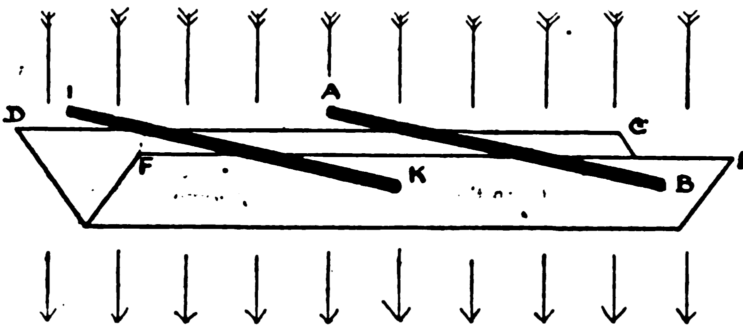

Fig. 3.

Similarly, if a second conductor I K were to be moved in the same direction as A B, and with the same velocity, and if it be the same length, we shall get an E.M.F. induced in it exactly equal to that induced in A B, and the current flowing across the trough will now be double what it was before, supposing the resistance of the trough to be negligible.

If, on the other hand, I K be moved in the opposite direction to A B, the E.M.F. induced in I K will oppose that in A B, and the currents in the conductors lying across the trough will no longer be in the same direction.

Let us now cut off the junction of the trough, and looking at it in plan, see it as in Fig. 4.

PLAN.

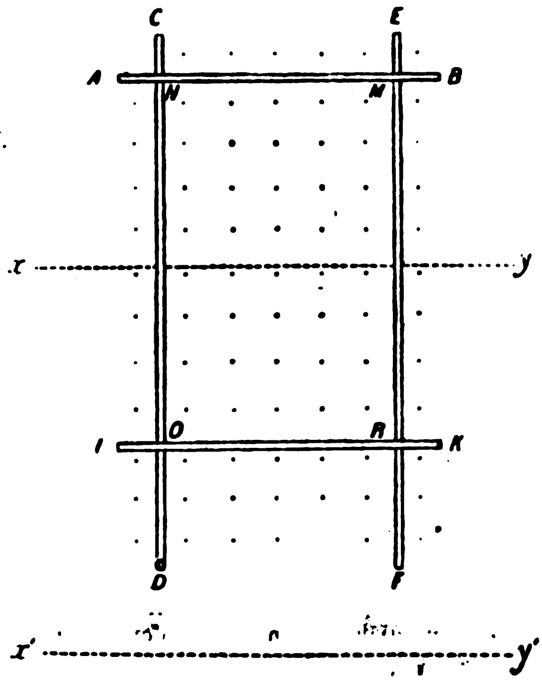

Fig. 4.

Now let A B move towards $x\,y$, and I K move in the opposite direction, then the induced E.M.F.'s will help each other, and we shall get a current flowing in the direction N M R O, due to the sum of the E.M.F.'s $B\,l\,v$ and $B\,l\,u$, where v and u are the velocities of the conductors A B and I K.

Now, suppose A B and I K were rigidly fixed to the connecting rails C D and E F; motion could not, of course, be imparted to them by sliding them along the rails, but a similar translation across the lines of force could be effected by causing the whole rectangle to rotate about an axis $x\,y$, situated in the centre of the rectangle and parallel to A B.

The velocity v across the lines of force at the commencement of the rotation will be almost zero, because the conductors A B and I K will, during the first instant, be moving in directions very nearly parallel to the lines of force, but as the rotation continues the velocity of movement across the lines of force increases and attains a maximum when the rectangle has moved through 90°, for then the movement is wholly across the field. If now v' represent the lineal velocity of rotation, the electromotive force induced in the rectangle at any instant would be $2\,B\,l\,v' \sin a$, where a is the angle which the plane of the rectangle makes with the horizontal plane. The value of this electromotive force varies every instant from the value 0 to the value $2\,B\,l\,v'$ and back again to 0 as the rectangle completes half a revolution. As the rect-

angle performs the other half revolution the velocities across the lines of force change their signs, and accordingly the electromotive force in the rectangle gradually varies from 0 to $-2\,B\,l\,v'$ and back to 0. The currents in the rectangle, of course, during a complete revolution vary with the electromotive force from

$$0 \text{ to } \frac{2\,B\,l\,v'}{r},$$

back to 0, then to

$$-\frac{2\,B\,l\,v'}{r},$$

and back again to 0, attaining the maximum values at 90° and 270° with the horizontal.

Now, to go back again to the rectangle with the sliding ends, we see that if I K move in the same direction as A B, and with the same velocity, the electromotive force induced in it, counteracts that produced in A B, and no current results. If, however, I K moved with a less velocity than A B, the electromotive force induced in it would be less than that induced in A B, and accordingly a current would circulate in the direction N M R O, due to the preponderance of the electromotive force in A B over that in I K. The electromotive force in the circuit would then be $B\,l\,v - B\,l\,u$ and the current

$$\frac{B\,l\,v - B\,l\,u}{r},$$

These conditions can be fulfilled in the case of the rigid rectangle by causing it to rotate about an axis $x'\,y'$, situated outside the rectangle but parallel to A B.

The velocities of A B and I K *across* the field will at first be each equal to zero, and will, as before, attain their maximum values when the rectangle has completed a quarter of a revolution, but the velocity of I K will always be less than that of A B, because its distance from the axis of rotation is less.

Practically all generators for continuous currents are constructed upon one of these two types, the former being typical of the *drum armature*, which consists essentially of a coil rotating about an axis situated symmetrically *inside* it, and the latter, of the *ring armature* where the coil rotates about an axis *outside* it.

Such armatures are rotated in magnetic fields which are made as intense and as uniform as practicable.

There are, however, a large number of dynamo machines intended only to give alternating currents, and in such machines the movable conductors are made to traverse magnetic fields which are constantly varying in intensity and altering in polarity.

Such a field would be produced if several magnets were placed vertically below the moving conductors, with their poles arranged as shown in Fig. 5. The vertical field produced by N_1 would be most intense at the point occupied by the present position of

the conductor A B, and if A B were to move along towards D and F it would pass through a field gradually diminishing in intensity as it receded from N_1, but at a position half way between N_1 and S_1 it would begin to enter a field of reversed polarity and of gradually increasing strength. Therefore the current induced in A B would at first be in the direction B A, and after passing the central position a_1b_1 would change direction and be from A to B. It would be at a positive maximum at the original position, zero at a_1b_1, and at a negative maximum on passing S_1.

Now the conductor I K, if it moved along with the same velocity and in the same direction as A B, would be passing a south pole while A B was passing a north pole, and *vice versa*, and, therefore, the current produced in it would not oppose but assist the

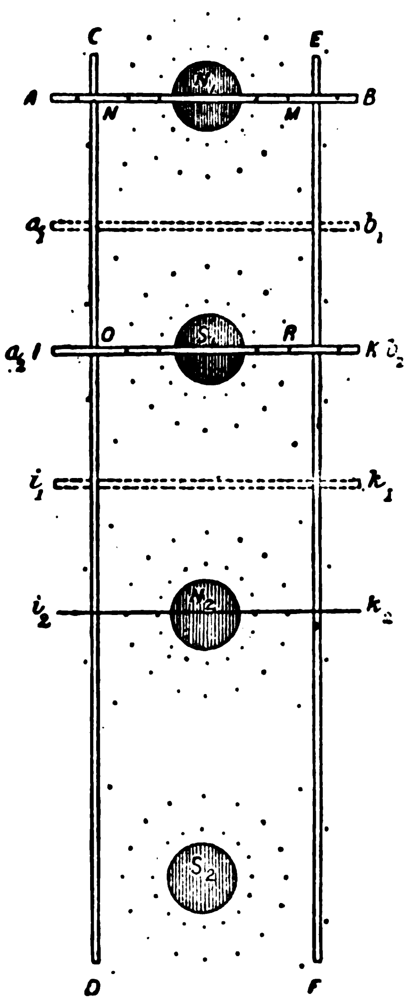

Fig. 5.

current produced in A B, both circulating round the rectangle M N O R in the same direction. The current would diminish to nothing as the rectangle approached the position $b_1a_1i_1k_1$, and then would become reversed and increase to a negative maximum as the rectangle arrived into the position $b_2a_2i_2k_2$.

This state of things could be produced in a rigid rectangle if it were made to slide over the periphery of a wheel, the spokes of which were magnets.

As alternating current dynamos have practically no service applications at present, they will not be further referred to, and we shall confine our attention to continuous current generators such as are used in the Service.

Such a generator consists essentially of three parts, which will be discussed *seriatim*—(*a*) The armature or collection of conducting wires in which the E.M.F. is induced; (*b*) the field magnets, or that part of the generator which provides the magnetic field in which the armature is rotated; and (*c*) a device for suitably applying the E.M.F.'s induced in (*a*) to the external circuit, known as the commutator, the necessity for which will be apparent when dealing with armatures.

CHAPTER II.

ARMATURES.

REFERRING back to the two types of armatures mentioned in the last chapter we see that the drum armature is based on the principle of the revolution of the rectangular coil A B K I (Fig. 4) about an axis $x\ y$ situated within the coil.

Regarding Fig. 4 now as an elevation and not a plan, if the rectangle revolve so as to cause A B to approach in front of the paper and downwards, and I K to pass through to the back of the paper and upwards, and if the lines of force proceed from a north pole in front of the paper through the rectangle towards a south pole at the back of the paper, then the current in A B will be from A to B, while the current in I K will be from K to I. so that a current will circulate round the rectangle in the direction N M R O.

This will continue until A B and I K have exchanged positions, when the direction of the current will also change. This movement of the rectangle is shown in Fig. 6.

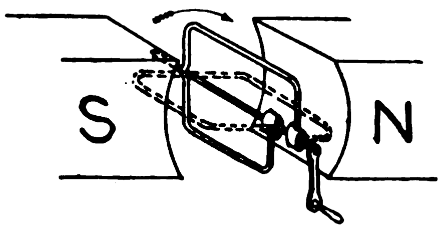

Fig. 6.

If now we arrange to collect the E.M.F.'s induced in the coil and apply them to some external circuit, we must divide the coil and connect its ends to two rings, against which can press collecting " brushes " as the coil revolves.

Let this be done as in Fig 6 ; then, assuming the intensity of the field and the angular velocity are uniform, when the coil revolves, the electromotive force induced in it is a maximum when the plane of the coil is passing the poles N and S, because here the wire is cutting the lines of force perpendicularly, and here

$$E = 2\,B\,l\,v$$

where l is the length of one side, B the intensity of the field, and v the lineal velocity, but in any other position

$$E = 2\,B\,l\,v \sin \alpha$$

where α is the angle between the plane of the rectangle and the vertical plane through its axis.

Hence the electromotive force in the coil at any moment varies as sin α, that is, will, if graphically represented, have the appearance shown in Fig. 7, which is a curve of sines where the horizontal *abscissæ* measure the magnitudes of the angles and the ordinates the values of the sines of those angles.

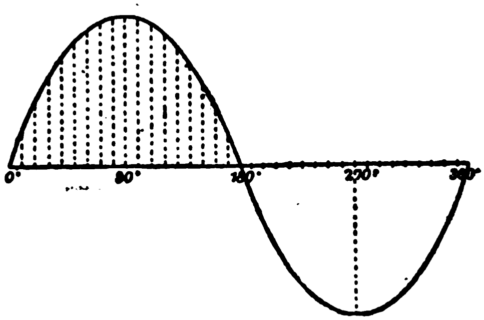

Fig. 7.

The current in an external circuit, consisting of a *simple* resistance, would vary in a similar manner, and be alternating in direction, and it is in order to overcome this that the necessity for the "commutator" arises.

This in its simplest form is shown in Fig. 8, and consists simply of two hollow half-cylinders, against which two springs, or brushes as they are termed, are made to press, and these brushes are connected to the external circuit. They are shown in Fig. 9.

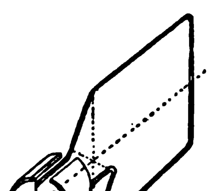

Fig. 8.

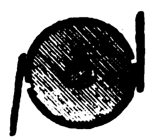

Fig. 9.

This is called a two-part commutator. It has the property of annulling the effect in the external circuit of the reversal of the electromotive forces in the rectangle when the latter changes its position. For the upper side of the conducting rectangle arrives at the position now occupied by the lower side at the same instant as that at which the electromotive force changes direction; but so also at that instant do the springs slide off one cylindrical plate to the other. In consequence, that portion of the rectangle in which the electromotive force is of one sign is always in

connection with the upper spring, and that in which the electromotive force is of the other sign, is always in connection with the lower spring.

This gives rise to a current in the external circuit which is always in the same direction, but of a pulsating nature, as shown in Fig. 10.

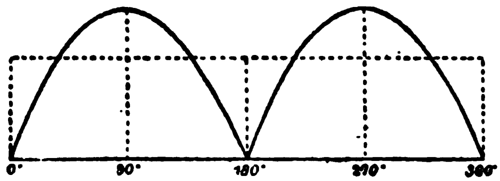

Fig. 10.

The difference of potential at the commutator plates due to the electromotive force induced in the rectangle, can be increased by using a coil of wire instead of a simple rectangle, and by connecting the ends of the coil with the commutator plates. Fig. 11 shows a coil consisting of two turns, in which the electromotive force would be doubled, and Fig. 12 shows a coil of many turns, in which the electromotive force would be multiplied as many times.

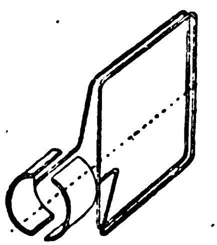

Fig. 11.

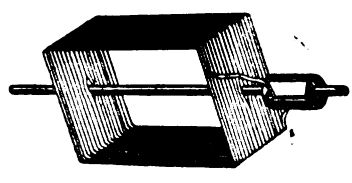

Fig. 12.

Now, if the rectangular coil shown in Fig. 12 be wound upon an iron core, the effect is very much further to increase the electromotive force.

The object of the iron is to assist the magnetic circuit, and thus intensify the magnetic field. The iron has, in fact, as compared with air, a much greater capacity for carrying magnetic lines, or lower reluctance (see Chapter III). As compared with air, therefore, iron may be said to have a multiplying power over the lines, which multiplying power depends (among other things) on the quality of the iron. We have already seen that

$$E = B \times l \times v,$$

therefore if l and v are unaltered, as B is now largely increased by the presence of iron, E will obviously increase also.

The original Siemens shuttle-wound armature consisted simply

of a rectangular coil, similar to that shown in Fig. 12, wound upon an iron core with a groove cut in it for the coil. This, when supplied with a two-part commutator gives rise to a pulsating current, always in the same direction as regards the external circuit.

All the exploders used in the service for firing mines have armatures of this pattern (*vide* Fig. 13).

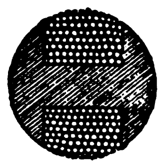

Fig. 13.

It will be observed that, so far as furnishing electromotive force is concerned, the wire at the ends of the rectangle is idle, and only offers useless resistance to the current, but it is necessary to the arrangement, for otherwise the circuit would not be continuous. Therefore, from this point of view, the longer the rectangle is in comparison with its breadth, the more economical it is. But there is a limit to the attenuation of the coil or armature fixed partly by mechanical difficulties of construction, and by the decrease of lineal velocity produced when the diameter is very small, and partly by the conditions for economy in the shape of the field magnets. A common proportion is for the length to be rather greater than the diameter.

An early attempt at improvement was to add another set of coils at right-angles to the first, as shown in Fig. 14. The commutator is divided into four plates, and the brushes adjusted so as to touch the centre of the commutator plates attached to the coil which is undergoing maximum induction.

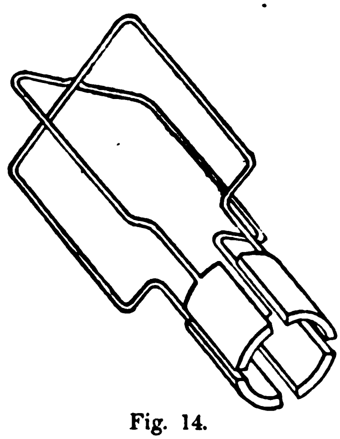

Fig. 14.

In this arrangement each coil is put into connection with the

brushes by the commutator at the time during which it is most usefully employed in generating electromotive force, and cut out of connection when its motion is nearly parallel to the lines of force, or when its electromotive force is zero or very little.

The resultant E.M.F. is represented in Fig. 15,

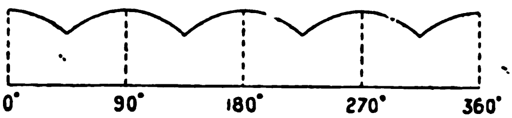

Fig 15.

causing a current in the external circuit, as shown in Fig. 16.

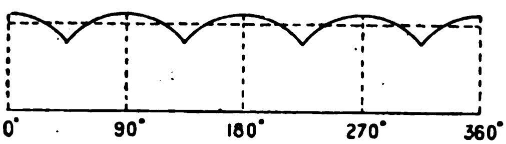

Fig. 16.

This current consists of more frequent pulsations, but instead of varying from zero to a maximum, they only vary from one value to another about $1\frac{1}{3}$ times as great. By further dividing the commutator into eight plates, and having two more coils making equal angles with the original two, we can still further diminish the fluctuations in the current, see Fig. 16, until, by employing a sufficient number of coils, we can get a current that is sensibly uniform.

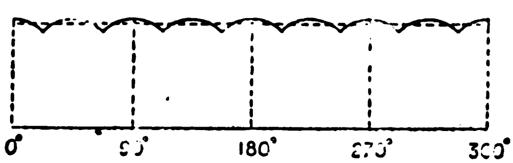

Fig. 17.

Now, by inspecting the curves in Fig 15, showing the E.M.F. available for use in the external circuit, and comparing with Fig. 18, in which the full curves are drawn, it will be seen that at

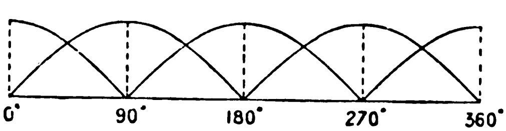

Fig. 18.

any instant some of the coils are generating a considerable amount of E.M.F., which is not being utilised in the external circuit, *i.e.* all the E.M.F. which is being generated during the motion of the coil from a position 45° on one side of the vertical to a position 45° on the other side of the vertical is being wasted.

Armatures of this kind are, in fact, a class by themselves. They are known as *open-coil* armatures, from the fact that there is no circuit round the armature, except that through the brushes and external circuit. They have considerable commercial application for arc lighting, for which they are well adapted, for reasons which need not be entered into here; as, however, they are not used in the service they will not be considered further.

The great improvement, however, in armatures for ordinary purposes was the collecting of those E.M.F.'s shown in the preceding type to be wasted, and the adding of them to the E.M.F. generated in the coil which happens to be under the brushes. This improvement was suggested by the invention of the "Gramme ring," which will be described later; in order, however, to complete the subject of the drum armature, we will anticipate the principle here.

First of all it is obvious that if, instead of attaching one coil to each of the pairs of commutator plates, we attach two, as in Fig. 19, we shall be employing two parallel coils, in each of which

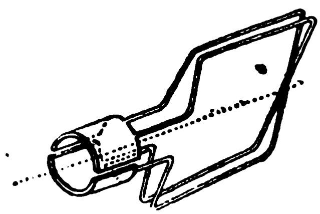

Fig. 19.

there will be excited an electromotive force equal to that excited in the coils in Fig. 8, and the result will be similar to that in the case of two cells of a battery which are connected up in parallel, in which case the resulting electromotive force in the circuit will be the same as that due to one cell, but the internal resistance will be halved.

But suppose, instead of doing precisely this, we make the arrangement which is shown in the next figure (Fig. 20).

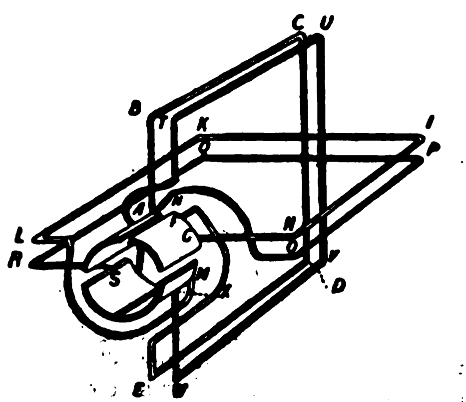

Fig. 20.

Here the ends of the coils, instead of being connected to opposite commutator plates, are connected to contiguous commutator plates. We still have the two parallel coils as before, each having excited in it the same electromotive force, but it will be seen that the whole forms two complete circuits in parallel.

Starting from A, the first circuit is A B C D E F G H I K L M, and the other is N O P Q R S T U V W X, the commutator plates A and M forming their common terminals. These two parallel circuits are precisely similar; each consists of a conductor in each of the four positions, D E, K L, B C, H I, and the electromotive force in each circuit is that due to the sum of the electromotive forces induced in all parts of it. There is, therefore, in this arrangement no electromotive force wasted, as there was in the arrangement shown in Fig. 14, and the resulting curve, instead of being that shown in Fig. 15, becomes one in which the ordinates of the two component E.M.F.'s are added together. The electromotive force at any time being the sum of the electromotive forces in the various parts of each circuit.

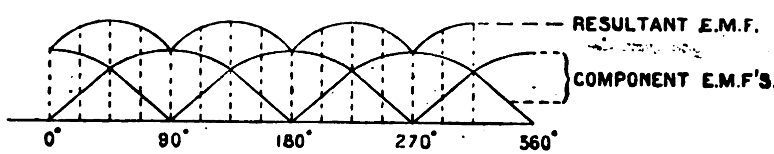

Fig. 21.

It will be observed that this arrangement furnishes a considerably greater maximum electromotive force than the open coil arrangement in Fig. 18.

All closed-coil drum armatures are developments of these principles, the number of coils and commutator plates being, of course, greatly in excess of those shown above, so great, in fact, that in a well-designed dynamo the pulsations become practically negligible. The drawings of the complete drum armature and connections are very complicated, and for a further consideration of this subject one of the large text-books should be consulted, such as Silvanus Thompson's "Dynamo Electric Machinery," or "The Dynamo," by Hawkins and Wallis.

We now come to the second type of armature, known as the Gramme ring, which is based on the principle of the revolution of the rectangle A B K I (Fig. 4) about an axis $x'\ y'$, situated outside the rectangle, but parallel to the sides A B and I K.

In this case, suppose the rectangle to revolve about an axis $x'\ y'$ in the plane of the paper, so as to approach towards the observer and downwards in front of the paper. Suppose, also, the lines of force to pass through the paper from a north pole in front of the paper to a south pole behind it. Then, as before, an electromotive force will be induced in A B in a direction from A to B, and one will also be induced in I K in the direction I K. These tend to oppose one another, and the resultant E.M.F. in the

rectangle is due to the difference between them. The electromotive force is greater in A B than in I K, because its rate of lineal motion across the lines of force is greater, and therefore the resultant E.M.F. has the direction N M R O.

Now, the Gramme ring consists of a number of rectangular coils of wire wound round an iron ring of rectangular section. Fig. 22 shows one such coil attached to a two-part commutator.

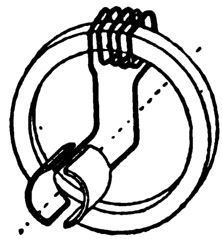

Fig. 22.

This arrangement corresponds to that shown in Figs. 8 and 12, and if it were revolved about the dotted axis it would give rise to a current in the external circuit which would fluctuate in strength according to the curve given in Fig. 10.

A coil may be wound between the same commutator plates in parallel with the above, having the same effect as the parallel coil in the Siemens armature (Fig. 19), viz., of halving the resistance of the armature without increasing the electromotive force. It is not necessary, however, to wind this second coil *over* the first, as in the Siemens armature, because, the ring being hollow, it can be wound on the opposite side of the ring, as shown in Fig. 23; and if due regard be paid to the direction of the

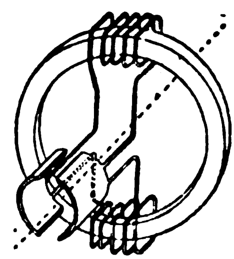

Fig. 23.

winding, and the connections with the commutator, the E.M.F. induced in the parallel coil will be in the same direction, as regards the external circuit, as that induced in the first.

The addition of another pair of coils and the further division of the commutator into four plates (Fig. 24), will have the same

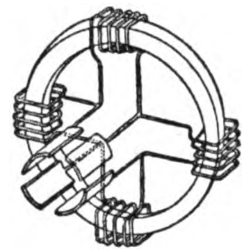

Fig. 24.

effect as the device of Fig. 20, and will produce an E.M.F. varying as shown in Fig. 21. Fig. 25 gives a representation of a Gramme armature with four pairs of coils, with which the fluctuations of the E.M.F. are still further reduced.

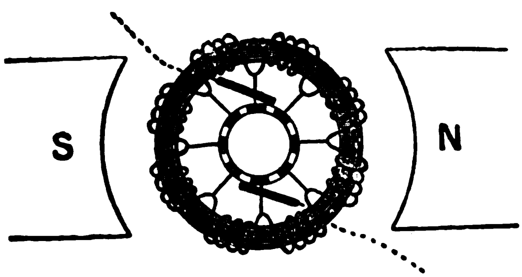

Fig. 25.

The construction of the Gramme ring armature naturally suggests the idea embodied in the description of Fig. 20, namely, that of making the whole armature one continuous circuit throughout, and thereby realising all the electromotive forces generated in all parts of it. It was, as has been stated, the invention of the Gramme ring which led to this great improvement in dynamo construction.

Fig. 26 shows the Gramme ring in its ideal simplicity where

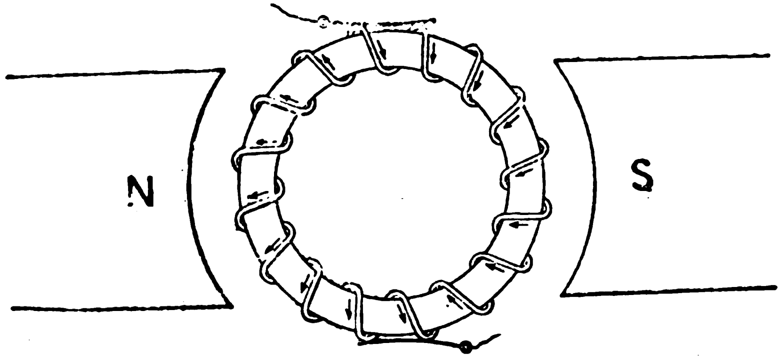

Fig. 26

the commutator is removed, and where the brushes make contact with the coils themselves. The continuity of the whole armature is fully apparent. When this ring is rotated in a magnetic field like that represented in Fig. 26 (the brushes remaining fixed), an E.M.F. is generated in each half of the ring. The E.M.F. on one side of the straight line joining the brush contacts is in the opposite direction from that on the other, since the movement of the conductor across the magnetic lines of force is in the reverse direction. But as regards the external circuit these two E.M.F.'s work in the same direction, like two cells in parallel. If the motion of the ring is in the direction of the hands of a watch the E.M.F.'s induced will be in the direction indicated by the arrows.

The induced E.M.F. per turn of wire is greatest in the coils opposite to the poles of the field-magnets (compare Fig. 6), for at these points the motion is at right angles to the lines of force. It is zero at the brushes. In the intermediate positions it varies according to the sine of the angular displacement from the brushes. The total effect of the dynamo-electric induction in the whole ring is similar to the effect produced by the total electromotive force of two series of voltaic cells of different electromotive forces. Supposing one represents a cell with a large electromotive force by a large cell, and those with less electromotive force by correspondingly smaller cells, as in Fig. 27, the parallel will be complete.

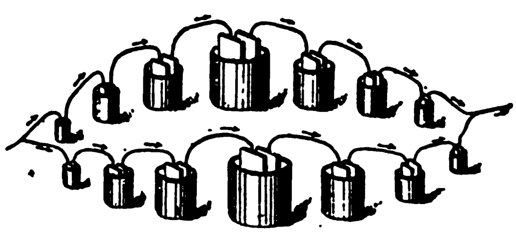

Fig. 27.

The brushes should be placed where the electromotive force changes sign, and where the induction is least. If placed where the electromotive force is highest the potentials of the brushes would be equal, and no current would take place in the external circuit.

In the original consideration of dynamo-electric induction (p. 10) it was noticed that the E.M.F. induced in that side of the coil nearer the axis of revolution opposed that in the further side, the effective E.M.F of the coil being the difference between them.

At first sight this would appear to be a very serious objection to the use of this kind of armature, and, were the field between the pole pieces of constant intensity throughout, no doubt this would be so; a consideration, however, of the effect of the presence of iron in the armature, will show how this objection practically disappears.

The iron in the armature offers a much easier path to the magnetic lines of force than the air does; the result of this is, that instead of the field being of uniform intensity throughout it is considerably distorted as shown in Fig. 28. The lines of force will be bent into the ring, traverse round the ring, and emerge at the other side: very few will pass across the open space inside the ring.

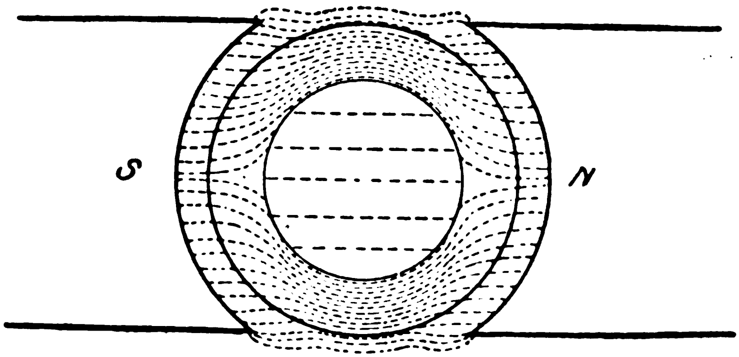

Fig. 28

Then, reverting to p. 10 where the effective E.M.F. of the whole coil was shown to be of the form

$$\frac{B l v - B l u}{r}$$

when B was supposed constant throughout, as B is no longer constant we must write

$$\frac{B_1 l v - B_2 l u}{r},$$

where B_1 is the intensity of the field traversed by the outer wire and B_2 the intensity of field traversed by the inner wire; this has been shown to be practically negligible, and the inner portions of the coil exert practically no *opposing* E.M.F. It must be remembered, however, that they offer an idle resistance to the passage of the current.

Comparison of Drum and Ring Armatures.

Few ring armatures are constructed now as compared with drum. One of the chief disadvantages of the ring armature is the liability of damage to the insulation when stout wire is used owing to the hammering necessary to get it into place and close round the corners. In case of a burn out of a coil the ring armature is more difficult to repair.

The drum armature as usually wound in modern dynamos has every advantage as regards ease of winding and repair, it

is not, however, so well ventilated as the ring armature. For a more detailed consideration of the windings of armatures, *vide* Chapters XII and XIII, "Dynamo Electric Machinery," by Silvanus Thompson.

Multipolar Armatures.

A large number of dynamos are made with more than a single pair of field magnet poles. Some are made with two pairs, and some with three or four pairs. Such dynamos are termed multipolar dynamos. Fig. 29 gives a representation of a four-pole armature, the positions of the pole pieces being shown

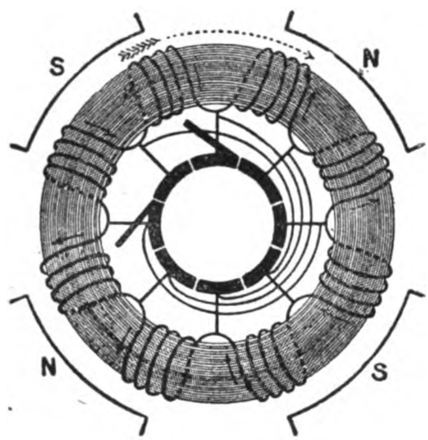

Fig. 29.

at S N S N. This armature may be considered to consist of two complete ring armatures coupled together in parallel, the upper half with the upper pair of poles constituting one, and the lower half with the lower pair of poles constituting the other

If the connections of the armature be followed round from brush to brush, it will be seen that instead of there being two parallel circuits, as in Fig. 25, there are four parallel circuits, each consisting (in Fig. 29) of the two coils immediately under each pole piece, together with their connections, direct or otherwise, to the brushes. The circular connections shown have the same effect as if there were four brushes placed round the commutator at intervals of 90°, and the opposite ones connected together by wires. In some four-pole dynamos this device of employing four brushes is adopted in preference to that of the circular cross connections, in order to avoid complicating the winding of the armature.

The electromotive force of a four-pole armature is only that due to the summation of the electromotive forces induced in one quarter of the number of coils in the armature, while in the two-pole armature it is that due to one half of the coils; but

since the current furnished by the machine has four paths in the armature instead of two, the section of the wire employed in the winding may be reduced to one half that of the wire in a two-pole machine, and so twice the number of turns can be made in the same space. The electromotive force of the armature will by this means be brought up to the same amount as in a two-pole machine. The resistance of such a four-pole armature is, however, the same as that of the similar two-pole machine, notwithstanding the reduced diameter of the wire in the coils. (There are also several methods of connection by which the coils can be placed in series, with a view to doubling the E.M.F., of course at the expense of the internal resistance.)

The "Victoria" machine is an instance of a four-pole dynamo, having cross connections in the armature and only two brushes.

The cores of the Gramme ring armatures are made of very various sections, from a nearly flat disc as in the earlier Victoria dynamos, to a hollow cylinder, or drum, as in most of the more modern two-pole machines.

Whatever the shape of the core may be, it is essential that the section should be sufficiently large to absorb all, or nearly all, the lines of force generated by the field magnets, and in order not unnecessarily to increase the size of the armature, the iron of which the core is composed must be of the purest and softest description, for then it is more permeable to the magnetic lines, and a smaller section will suffice. If this be not the case, some of the lines of force will pass outside the armature, and some will pass straight across the interior hollow of the armature. Those which pass outside are wasted, from which it follows that part of the energy derived from the machine and utilised to magnetise the field, is being wasted, impairing thereby the efficiency of the machine. Those which pass across the interior of the hollow are not only wasteful and detrimental to the efficiency, but they actually weaken the electromotive force of the armature, since they are productive of a counter electromotive force in those portions of the coils which lie in the interior of the ring.

Lamination of Cores of Armatures.

For precisely the same reason as that which causes currents to be induced in the coils of the armature, currents will be induced in the substance of the iron core upon which the coils are wound. These currents will circulate round the iron core in the same direction as those in the coils. They will have a low electromotive force compared with those in the coils, since the latter make a considerable number of turns round the core, whilst the core itself can only be considered to consist of one turn. But since the resistance opposed to this electromotive force is very small, the resulting currents may become considerable. They are not directed into the external circuit, and therefore are doing no useful work,

their energy being only expended in heating the armature core, which already gets more or less hot from the currents in the coils. Moreover the currents in the cores are prejudicial to the efficiency of the dynamo machines, because it is at the expense of the power exerted by the steam engine that they are generated. It therefore becomes desirable to eliminate them if possible. This is done by dividing the iron of the core into laminæ formed by planes at right angles to the direction of the induced E.M.F.'s, and insulating the laminæ from one another. Since the electromotive force in any of these laminæ is slight, sufficient insulation is obtained by varnishing them; and indeed sometimes the natural oxide which forms on the iron is found to be sufficient to reduce the currents to an inappreciable magnitude.

These currents are called "Foucault" or "eddy" currents.

The lamination of an armature depends upon the direction of the lines of force which enter the armature. Thus a drum armature consists of a number of discs of iron placed one upon another on a common axis, this axis being the axis of rotation of the armature. In an ordinary Gramme ring the lamination is effected by superimposing upon one another a number of flat rings; whilst in those armatures intended to be rotated between pole pieces of the Victoria type, the core must be built up of iron tape coiled on a strong foundation ring, for the magnetic lines of force enter from three directions.

If the armature coils are made of very stout bars of copper, such as would be required for machines furnishing very large currents, not only must the cores be laminated, but the copper bars must also be subdivided to reduce the eddy currents in them.

Armature Coils.

The coils of the armature must, of course, offer as little resistance as possible to the passage of the current, in order that the percentage of power lost in driving the current through the armature, and the consequent heating of the coils, may be as small as possible. For this purpose they must be made of copper of a high degree of conductivity, and should be as short and thick as is consistent with obtaining the electromotive force required at a reasonable speed.

Armature coils should not be wound too closely to one another, for since it is impossible so to reduce their resistance as to eliminate all heating, it is necessary to provide spaces which are constantly being ventilated as the armature revolves rapidly in the air.

The insulation of the coils from one another, and from the core, should be effected by means of some substance which does not become injured by a rise of temperature.

Since the centrifugal force acting on the parts of the armature is very considerable, care must be taken both to render the construction mechanically as strong as possible, and to balance the armature very exactly on its axle.

Ring armatures must of necessity be built up on some sort of spider, in practice made of gunmetal, so as not to encourage lines of force to flow across the space inside the ring. The limbs of the spider suffice for driving horns for the conductors.

Drum armatures may be built hollow on spiders or built up solid. Driving horns for the conductors must be provided, either let into the core or left projecting from an occasional stouter sheet used in building up the core, or the conductors themselves may be placed, and secured, in suitable slots or tunnels provided for the purpose in the armature core.

CHAPTER III.

MAGNETIC INDUCTION.

It was stated in Chapter I that it had been conventionally arranged to represent a magnetic field of unit intensity as containing one of the imaginary lines of force per square centimetre of cross section. Such a unit field is produced at a distance of one centimetre from a magnet pole of unit strength. If such a pole belong to a long thin bar magnet, of which the other pole is far distant, all the lines of force from the pole will radiate into space at equal angles with one another, so far as the region immediately surrounding the pole is concerned, and will produce a field of unit intensity at every point on the surface of a sphere of one centimetre radius, described with the pole as a centre, that is, will produce one line per square centimetre of the sphere's surface; and, since there are 4π square centimetres of surface in the sphere, there will be 4π lines cutting the sphere. All these lines will form closed circuits. They are considered to originate from the north pole, where they emerge into space and describe curved courses, gradually bending round until they arrive at the south pole. From this point they all collect together and traverse the interior substance of the magnet from end to end to the point whence they originally started. This is shown in Fig. 30. If the

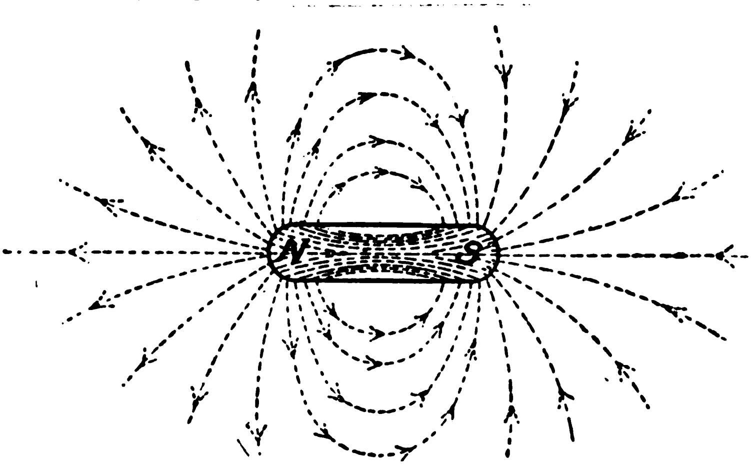

Fig. 30.

strength of the magnet pole be m, it will give rise to $4\pi m$ lines of force.

Now, a wire conveying a current of electricity will behave in a similar manner to a magnet in giving rise to a magnetic field or to lines of magnetic force. These lines will, in the case of a straight wire carrying a current, circulate round the wire in a series of parallel circles with their centres in the axis of the wire (see Fig. 31). If the wire be bent into the form of a circular ring, all the lines on the concave side will be condensed together within

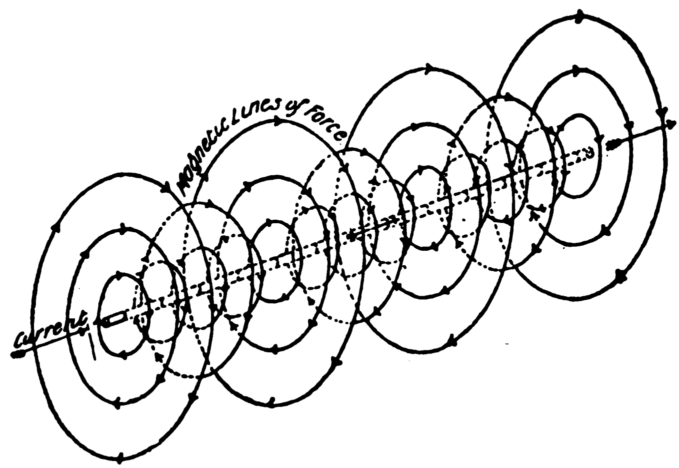

Fig. 31.

the circle (as in Fig. 32, which shows only a few of the lines). Now, the disposition of the lines in this case immediately suggests a parallel between the circular current and a very short magnet of large diameter; and it has been shown by Clerk Maxwell that a circular current produces exactly the same external field as that produced by a very thin section of a bar magnet, whose cross section is equal to the area enclosed by the current, and whose edges coincide with the position of the wire. These sections of bar magnets are called "magnetic shells."

If, instead of one single ring, we take a helix consisting of n turns, the number of lines of force is increased. It has been demonstrated that the number of lines generated through any section of a helix is

$$\frac{4\,\pi\,n\,A\,C}{l},$$

where l is the length of the axis of the helix, n the number of turns, C the current in C.G.S. units (each = 10 amperes), and A

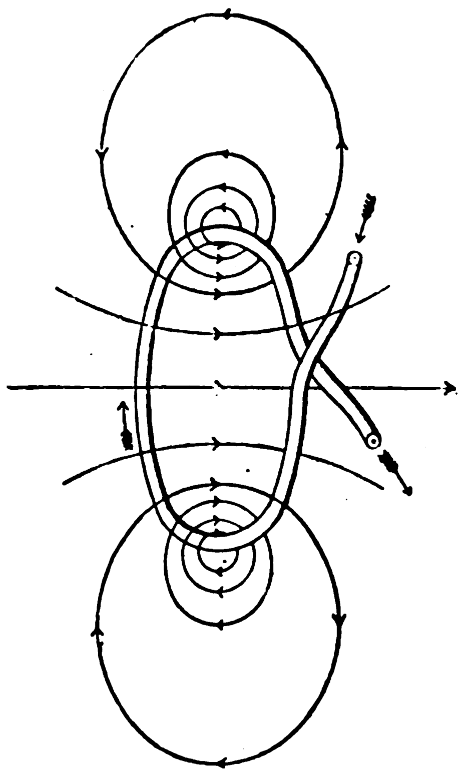

Fig. 32.

the area of the cross section; provided that the helix is so long that the distribution of the free polar magnetism at its ends does not need to be taken into account.

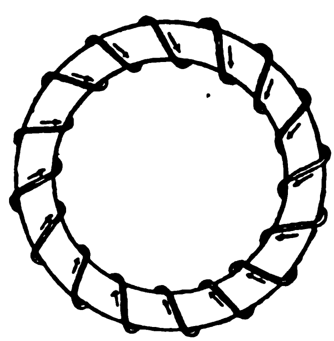

Fig. 33.

If the helix be bent round till its ends meet so as to form a closed circuit (Fig. 33) it will have no polar ends, and will, in fact,

if the winding is very close together, exhibit no external magnetic properties at all. Then, if the core be of wood or other non-magnetic substance, the expression

$$\frac{4 \pi n A C}{l}$$

exactly represents the number of lines of force generated within the coils, l being, in this case, the length of the circumference of the curve described by the axis of the helix.

The total number of lines of force induced through a helix is called the "total magnetic induction," and is usually denoted by N, the intensity of the magnetic induction at any point of the cross section being represented by B.*

In the case of a helix without an iron core, the intensity of the magnetic induction B also measures what is called the "magnetising force" of the helix, usually denoted by H. But if the helix enclose an iron core, the case is very different. The magnetic induction is enormously increased without there being any increase in the magnetising force. It is as if iron possessed a multiplying power analogous to the multiplying power of glass, mica, ebonite, and other dielectrics for statical electric forces. Iron, in fact, possesses a sort of increased magnetic conductivity, or "permeability," similar to the superior power possessed by solid dielectrics for conveying lines of electric force. The intensity of the magnetic induction B now becomes equal to the magnetising force H, multiplied by a coefficient μ, which is called the "coefficient of permeability," and the number of lines N generated by a current C flowing in a helix of n turns round an iron core of length l, and sectional area A will be

$$\mu \times \frac{4 \pi n A C}{l}.$$

The coefficient μ varies not only with the class of iron employed, but also with the magnetic state of the iron. It is very large for but slightly magnetised soft iron, and gradually decreases towards a value 1 as the iron approaches magnetic saturation. The symbol μ always expresses the ratio of the intensity of the magnetic induction evoked to the magnetising force.

It is supposed that all magnetisable substances consist of molecules which are always magnetised, that is, are little magnets having a pole on each side. It is further considered that, when the mass exhibits no external magnetic properties, the molecules are indiscriminately arranged within the mass with their poles pointing in every direction, but so that, taken in the aggregate, they neutralise one another, or, in other words, form closed magnetic circuits.

It is the function of the magnetising force to move the molecules

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* It should be noted that B is far from being uniform across the whole cross section. Fig. 32 shows that B is more intense in the neighbourhood of the wire than in the centre of the coil.

until they all face one way, and by destroying the continuity of the magnetic circuits within, to cause the iron, as a mass, to exhibit free polarity. This function is resisted by the molecular forces, which may be considered to remain nearly constant. As the molecules turn round in obedience to the magnetising force (which is always in the direction of the resulting magnetism) the force always acts at an increasing disadvantage. An increment in the force will not produce a proportional increment in the magnetism evoked. It will take an infinite force in the direction of the axis of magnetisation to turn the molecules the last infinitesimal portion of their path, so as to make them all face in the direction of the axis.

When all the molecules face in the direction of the axis, the magnet is then perfectly saturated. This ideal saturation is never reached with any finite magnetising force, but there is a limit which is reached sooner or later, depending on the mass of the iron, beyond which it is uneconomical to proceed further, and which is practically taken as the saturation limit.

If, therefore, at any point μ express the relation between the magnetism evoked and the magnetising force, μ must diminish as the magnetism increases.

If now the relation between B and H be plotted in the form of a curve for various values of H, we shall get a diagram showing the various changes undergone by the molecules of the iron, and many useful facts may be deduced from a careful study of such curves.

As μ varies with different sorts of iron and steel, of course these diagrams will differ in shape for the different materials.

Fig. 34 shows the results of some experiments made by Professor Ewing on a specimen of wrought-iron in the form of a ring as in Fig. 33.

Commencing with the iron completely demagnetised, a very weak current is passed through the surrounding solenoid, and the value of H calculated from the formula

$$\frac{4 \pi n C}{l}.$$

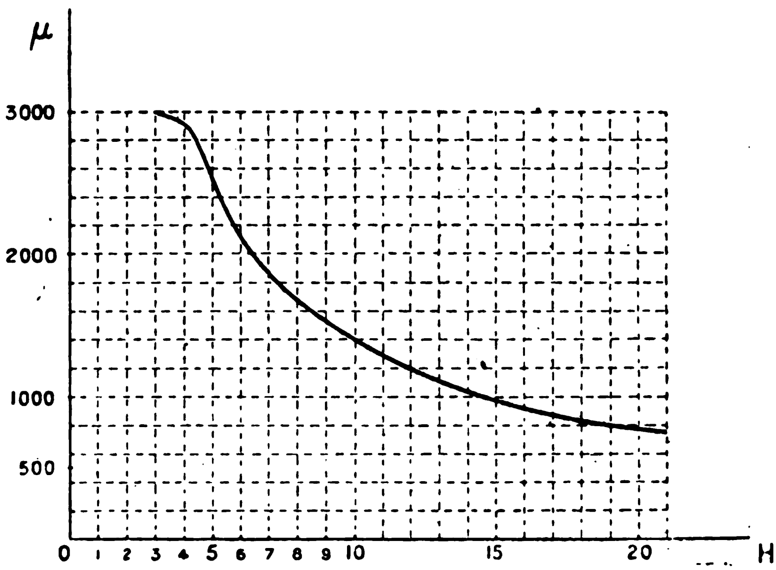
The corresponding value of B in the specimen is measured by a test with a "ballistic galvanometer," which need not be entered on here.

The value of H is now gradually increased by small steps, and the corresponding values of B observed and the points plotted, producing the firm line shown O K L M N.

Let us follow this curve from the origin O to N.

At first with weak H, the molecules of the iron evince a dislike to leaving their original mutual ties, at this period up to K in the diagram, μ is not much greater than 1.

The outside molecules (which may be supposed to be comparatively loosely knit together) begin to give way at this point, and in so doing influence those near them, and so on throughout the mass, which is now, so to speak, in a condition of very unstable equilibrium. The result of this is that a very small increase in H



Curve of μ and H.

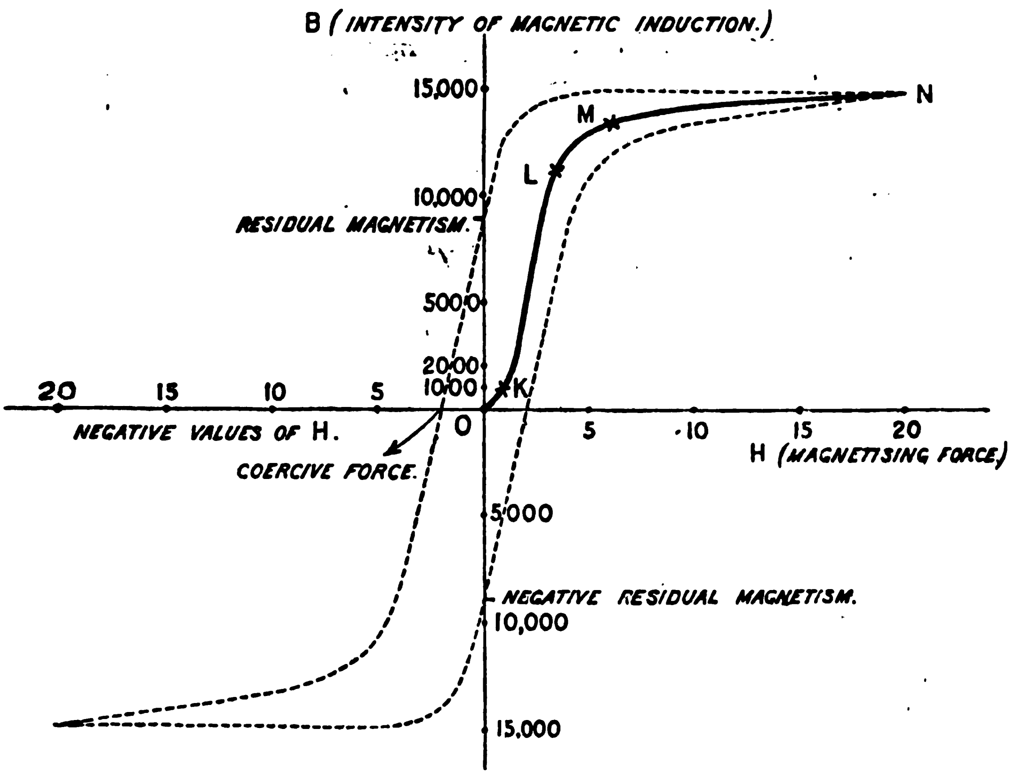


Fig. 34

now produces a relatively very large increase in B, and the curve rises very rapidly up to L in the diagram.

Still increasing H, it is noticed that now the curve does not rise as rapidly as before, the reason of this is that "saturation" is being reached. After passing point M on the diagram the curve flattens out still more, until at point N we have reached practically total saturation and the curve becomes asymptotic* to the line parallel to the horizontal axis. It is, in fact, uneconomical to further increase H with this particular specimen of iron. Fig. 34 gives also the curve of μ and H.

If now H be gradually decreased the curve will not descend exactly as it rose, and when H is decreased to zero we find the value of B remains about 10,000. This is called the *residual magnetism* (vide left hand dotted curve). The amount of residual magnetism depends on the substance. Soft charcoal iron may, according to Prof. Ewing, if carefully handled retain more than 90 per cent. of the magnetism induced, but its powers of retentivity are small and easily disappear. Steel, on the other hand, although possessing a much smaller value of μ is marvellously retentive, the more so the harder it is, but if very hard it is difficult to magnetise at all (the molecules would appear to be so firmly knit among themselves as to refuse to relinquish their original ties).

In order to destroy the residual magnetism in the iron under discussion, we must reverse the direction of the magnetising force, *i.e.* apply a negative magnetising force. By gradually increasing this we reach a point where B again is zero. H is now = − 2. This is sometimes called the *coercive force*, and is a measure of the tendency of the material to retain permanently the magnetism imparted to it. As has been stated, this is very marked in the case of hard steel and may be as much as H = − 40.

If H be further increased to a negative maximum, again reduced to zero, and again increased to a positive maximum, the specimen is put through what is called a complete "magnetic cycle," and the various values of B form a closed curve as shown by the dotted lines. The peculiarities of iron when put through such cycles are of the greatest importance in the construction of dynamo-electric machinery. Work has been done in putting the iron through a cycle, and the area of the closed curve is a measure of the amount of work that has to be so done. This work is manifested by the development of heat in the iron.

The iron, it will be noticed, exhibits throughout the cycle a peculiarity of "lagging behind" of effect after cause, *i.e.* B lags behind the H producing it. This peculiarity is termed "*hysteresis*," and the effect is evidently to complicate the relations between B and H, for an investigation of the figure will show that there may be as many as three different values of B for one value of H. For purposes of ordinary calculation, however, the values of B and μ are taken from the curve shown in firm lines ascending from zero.

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* This is due to the scale for H being much larger than that for B, were the scales the same the curve OKLMN would continue to rise for increasing values of H.

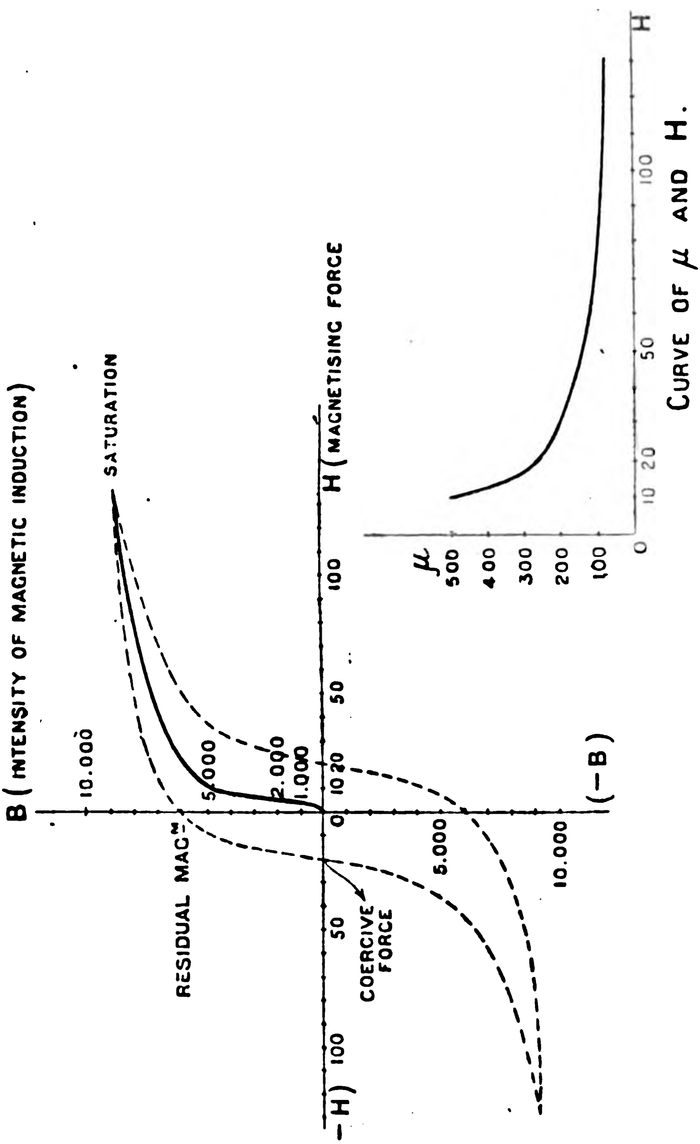


Fig. 35.—Magnetisation Curve of a Specimen of Cast Iron.

Fig. 35 gives a B H curve and also a μ H curve for a specimen of cast-iron, which may be contrasted with that for wrought-iron.*

There is a very marked analogy between the laws of magnetic circuits and the laws of ordinary electric circuits.

As has been already stated, μ is the "coefficient of permeability"; and we can say that $B = \mu H$; where B is the intensity of magnetic induction at any point, H the magnetising force, and μ the "coefficient of permeability," as before mentioned. The reciprocal of

$$\mu, \text{ or } \frac{1}{\mu}$$

will be a measure of the specific reluctance of the substance under consideration to carry the magnetic lines, and we may call this r and write

$$B = \mu H \text{ or } \frac{H}{r}$$

for each element of the circuit.

As has been already stated, the value of B generally varies between point and point of the cross-section of the magnetic circuit, since the value of H varies in this way, but the total flux across the whole of the cross-section of the circuit is the same at all points of the circuit.

The total flux in the circuit (represented by N) can be arrived at by the integration of all the forces causing the magnetism, and all the reluctances of the various parts, and we may say

$$N = \frac{\text{M. M. F.}}{R}$$

where M. M. F. stands for magneto-motive force, *i.e.* that which tends to force magnetism through a circuit, and R stands for the total reluctance, which, as in the case of ohmic resistance, varies directly as the length and inversely as the cross-section of the substance considered.

This is a magnetic equivalent of Ohm's law and has important practical applications in the design of dynamo-electric machinery.

It will be as well to remember that, when working in the practical units derived from the C. G. S. system, that the M. M. F. of a coil of wire is very approximately 1·25 times the ampere-turns.

In order to get the flux as large as possible with a given magneto-motive force, the reluctance must obviously be reduced as low as possible. With a given quality of iron this can only be done by having the magnetic circuit sufficiently large in cross-section and continuous, or as continuous as is possible. In a generator the magnetic circuit cannot be continuous, as the armature has to revolve in the field, but the air spaces are kept as small as possible consistent with clearance, and all joints in the iron are carefully machine-faced so as to be as close a fit as

* In contrasting the two curves of Fig. 35 with those of Fig. 34 attention is directed to the relatively higher values of H per scale division in Fig. 35.

possible, and thereby keep down the reluctance, for any space left means the introduction into the magnetic circuit of air, or some other substance, of a much smaller μ, and consequently higher reluctance than iron.

For further information on these subjects the following text-books should be consulted:—

Dynamo-Electric Machinery: Silvanus P. Thompson (Spon).
The Dynamo: Hawkins and Wallis (Whittaker).
The Electro-Magnet: Silvanus P. Thompson (Spon).

CHAPTER IV.

FIELD MAGNETS.

The magnets used for producing the powerful magnetic field in which the armature is to be revolved are called the "field magnets." They may be either permanent magnets (Fig. 36) or

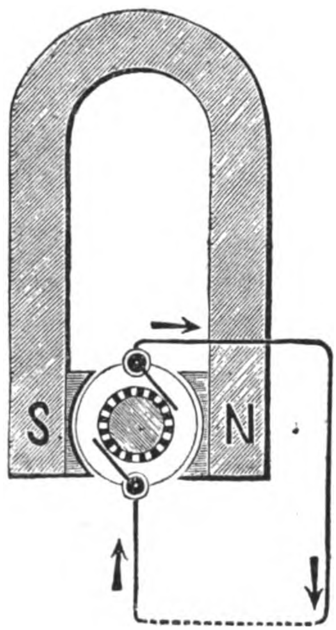


Fig. 36

electro-magnets (Fig. 37). Weight for weight, however, permanent magnets are not so powerful as electro-magnets; the latter are therefore exclusively used where weight and bulk are of consideration. If the field magnets are magnetised by means of a current furnished by a battery, or by another machine, the dynamo is said to be separately excited (Fig. 37). If the field magnets are excited by the current from the armature, the machine is called "self-exciting" (Figs. 38 and 39). Generally speaking, self-exciting dynamos are found more convenient. In these a portion, or the whole, of the current from the armature is passed round the field magnet coils. Self-excitation is made possible by the fact that iron having once been magnetised does not lose the whole of its magnetism on the cessation of the magnetising force,

a small amount called residual magnetism remaining for a very considerable time. When the armature is revolved in the weak field produced by this residual magnetism, a feeble electromotive force is induced, which drives a current round the field magnet coils in such a direction as to increase the magnetism; this increases the field, and consequently the electromotive force, and a larger current circulates round the magnets, and so on until the machine is fully excited.

This process is known as "building up" and may, in the case of large machines, occupy a considerable time.

It may be found that a machine refuses to "build up." This means that it has entirely lost its residual magnetism, and must

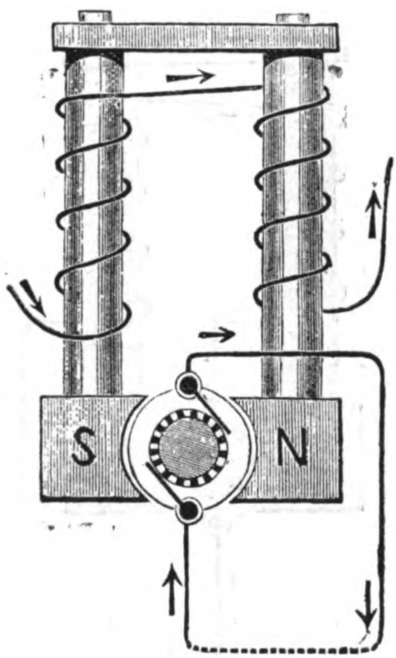


Fig. 37

be started by being given an initial magnetism, so to speak, by passing a current from some other electrical source, such as cells, through its magnet coils for a moment, care being taken that the current be so applied as to magnetise the machine in the proper direction (*vide* Chapter VII).

The name "dynamo-machine" was originally given to those machines in which the field magnets were self-excited without any extraneous aid. The term is now extended so as to include all machines in which the current is produced by the expenditure of mechanical energy, whether the field is produced by permanent magnets or by electro-magnets either separately or self-excited.

Self-exciting dynamos may be "series wound," "shunt wound," or "compound wound."

In the series wound dynamos (Fig. 38) the whole of the current from the armature passes a few times round the field magnet. In the shunt wound dynamo (Fig. 39) a small portion only of the current passes round the magnet coils a great number of times, the coils being in divided with the external circuit. These two machines are evidently suited to be used in different ways; a series dynamo will not excite till the external circuit is complete, and then only when the resistance in it is below a certain amount, called the "critical resistance;" on the other hand, the shunt machine excites best on open circuit, and its power gradually falls off as the external resistance is reduced. A shunt machine is evidently unsuited for working an arc, as the

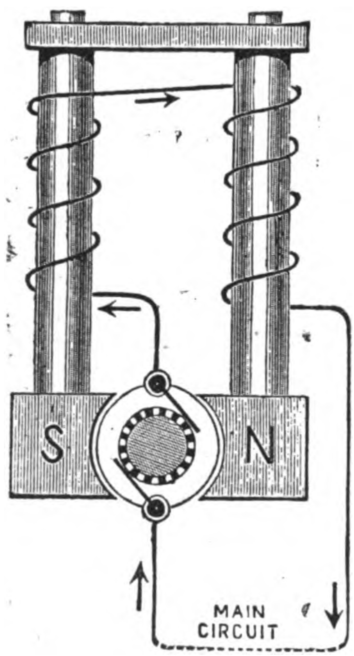


Fig. 38.

machine loses nearly all its magnetism just at the important moment when the carbons are brought together to start the arc. A series dynamo will keep and start an arc very well, but the fact that the machine does not excite till the carbons are closed is a disadvantage.

In the compound dynamo (Figs. 40 and 41) the field magnet is wound with both series and shunt coils so adjusted that at a constant speed the difference of potential at the terminals is very nearly the same whatever resistance is in circuit. Roughly speaking, this is brought about as follows:—On open circuit, and when there is a very large resistance in circuit, the magnetism is maintained by the shunt coils. As the resistance is reduced, the

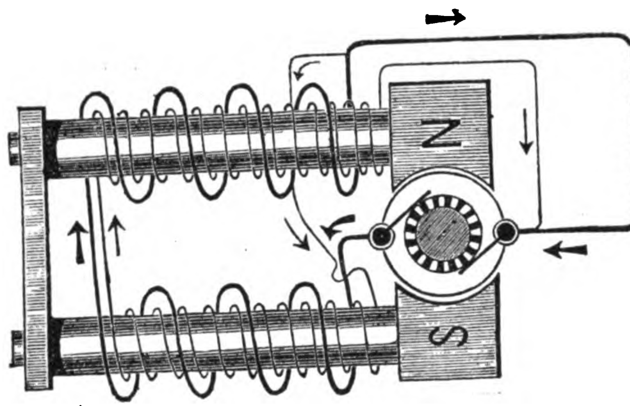


Fig. 41.

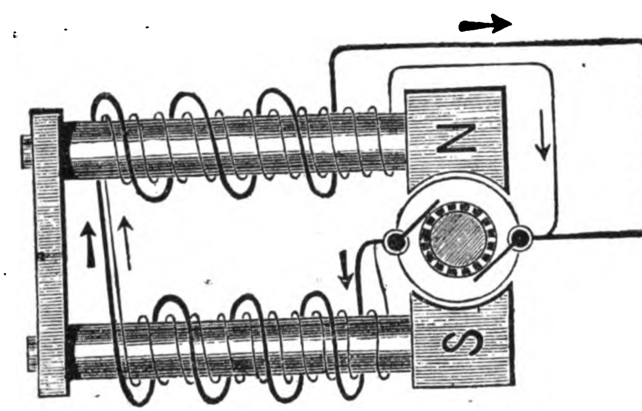


Fig. 40

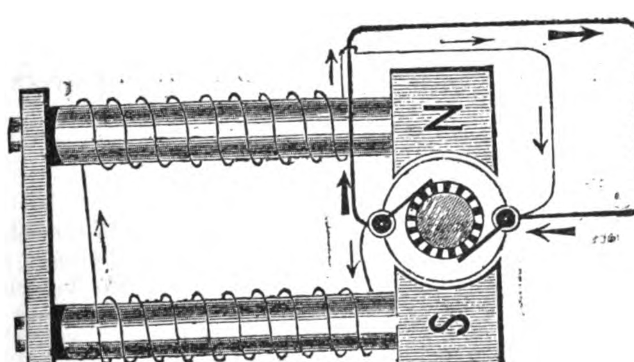


Fig. 39.

current in the series coils begins to make itself felt, and helps the shunt coils.

Machines are sometimes compounded with what are known as "long shunts," that is with shunt coils connected to the terminals of the machine instead of to the brushes. This is shown in Fig. 41. The arrangement makes the shunt rather more sensitive to variations in the external load, and for some purposes this is an advantage.

The manner of compounding a dynamo may be left until after a consideration of the peculiarities of the different types of machines.

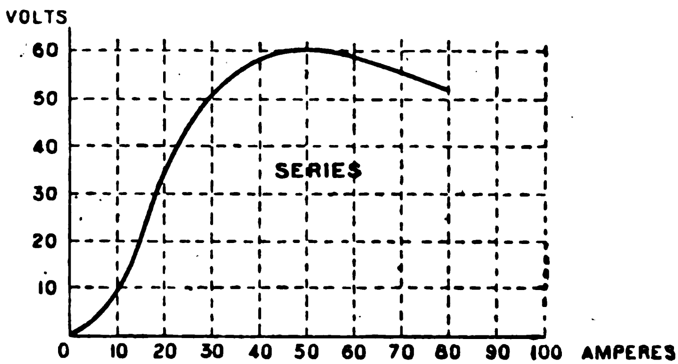


Fig. 42.

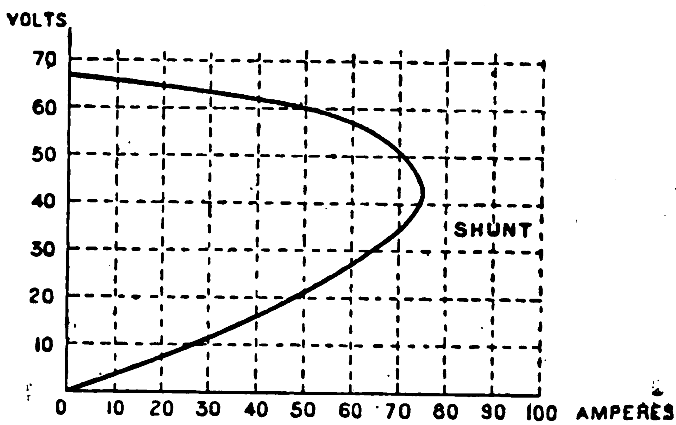


Fig. 43.

CHARACTERISTIC CURVES.

The relation between the volts at the terminals of a machine, and the current which it is supplying to the external circuit, may be plotted in the form of a curve. Such curves are known as *characteristic curves*, and give definite information regarding the peculiarities of the machines they are taken from.

Figs. 42 and 43 give specimens of such curves taken from a series wound and a shunt wound machine respectively.

In each case the maximum current output of the machine is supposed to be 50 amperes, at which current the machine should have a pressure of 60 volts at its terminals.

In following these curves the B H curve, Fig. 34, should be referred to.

Series Dynamo.

The machine is supposed to be running at constant speed. The external circuit is then so adjusted as to get various current readings, and at each reading the corresponding voltage across the terminals of the machine is noted and the results plotted into a curve.

In a series wound machine, before the external circuit is closed, there can be no excitation, apart from that due to the residual magnetism which will probably be very feeble. Starting then at the origin, with no external current we find no volts apparent; gradually increasing the external current, the iron of the magnets becomes more and more magnetised until at 50 amperes in the external circuit it is saturated. Up to this point the curve bears a marked resemblance to the firm line portion of the B H curve, Fig. 34. If, however, we increase the external current, instead of the curve continuing practically flat as in the B H curve, it droops downwards. The reason of this is that at no time in the measurements are we measuring the full volts generated by the armature. There has been in each case a CR loss due to the ohmic resistance of the armature itself. Now once the magnets have reached saturation, the *full volts* generated by the armature, at constant speed, remain constant, but the C R loss increases as we increase the external current; consequently the external volts decrease, since more are being absorbed in the armature, and the curve droops as shown.

Shunt Dynamo.

The curve here is curiously different from that in the series machine. In the case of the shunt dynamo it must be remembered that until the external circuit is closed the whole of the energy of the machine is being devoted to keeping up its excitation. We should, therefore, expect the volts to be higher now than at any other time. An inspection of the curve shows that this is so, and before the external circuit is closed the volts are nearly 70. Now in the shunt machine as the external current increases, so does the current through the shunt coil fall off in strength, *i.e.* (referring to B H curve), so does the H force fall off. Now looking at the B H curve, Fig. 34, at the top of the curve it will be noticed that the H force can be considerably reduced without materially affecting B, *vide* upper dotted portion of curve. This is what happens in the shunt dynamo; the fact that we start an external current, and the resultant diminution of the current in the shunt

coil, does not, up to a certain point appreciably diminish the strength of the magnetic field. The curve, it will be noticed, certainly droops a little, partly owing to the slightly diminished magnetism and partly owing to the increasing C R losses in the armature, until at 50 amperes in the external circuit the volts across the terminals are found to be 60. An increase of the external current beyond about 60 amperes, however, will be found to very quickly reduce the volts. The reason of this is that the magnetism curve has now reached that critical period where B falls very rapidly with a decrease of H (*vide* Fig. 34). As in this dynamo this fall in B re-acts on itself by further diminishing H, we get a curious result, a sort of opposite process to the "building up" of a machine spoken of earlier in this chapter. The result of this is that at about 75 amperes the volts suddenly decrease very rapidly and the machine becomes inert, nor will it do any more work until this external path is removed and so gives it a chance to build up again.

Compounding a Machine.

To compound a "long shunt" machine, it is run, before its series coil is wound on, but with the length of wire it is proposed to use for this coil connected in the circuit between one brush and one machine terminal, at normal speed, with its shunt coil separately excited with what is to be the normal voltage, and readings are taken of the volts across its terminals on open circuit and at various loads.

Suppose that on open circuit the volts $= E$ and at full load the volts $= E - e$, then, if the machine is to have a constant terminal P D at and up to this load, the magnetic field must be increased in intensity to such an extent that the deficient volts e are made up. Since the current is known, it is easy to calculate the number of turns through which this current must pass to give the required result. These additional turns are wound in series with the main circuit. By giving a few turns more than the calculated amount the P D may be made to rise with the current in the external circuit. The machine is then said to have a "rising characteristic," or to be "over compounded." Similarly, a few turns less than the calculated number will give a machine with a "drooping characteristic" or "under compounded."

Machines are often made on one of these principles, both of which have their uses for various sorts of work.

A "short shunt" machine has to be compounded in a slightly different manner.

Field Magnet Cores.

Theory shows that the field magnet should be heavy and massive. This is for two principal reasons: (1), the amount of magnetism which they are capable of holding is greater; and (2),

it reduces the magnitude and variability of the "lead," and consequently the amount of sparking at the brushes, considerations the bearing and importance of which will become apparent in Chapter V.

The use of plenty of iron ensures that saturation shall not be too soon reached, and that the magnetic resistance of the circuit shall be kept low. With the same objects in view the core should be made of soft iron; this is, however, not generally done on account of the expense, it being much easier to cast a magnet of the required shape. Cast iron has an advantage over soft iron in retaining more residual magnetism. This enables the machine to be more quickly and certainly excited. The cores of the D[r] Siemens machines are of soft iron, and consequently are much lighter than if they had been cast iron; these machines, however, spark considerably with variations in the load.

The core should be circular in section in order that as little wire as possible may be used to wind the necessary number of turns; with very thick magnets, however, it is considered advisable to make the section rectangular with rounded corners.

The single magnetic circuit is now generally adopted for bipolar machines. In order to reduce the magnetic resistance, the cores should (as before stated) be short and thick, and their poles or pole-pieces should be as close to the rotating armature as is consistent with safety in running. The air gaps and copper of the armature coils offer a resistance to the magnetic lines of force from 5,000 to 20,000 times as great as if the space were filled with iron.

The edges of the poles or pole-pieces should be rounded off, because corners invite leakage of the lines of force.

There should be no joints in the iron of the field magnet across the direction of the lines of force; if joints are unavoidable they must be carefully planed true and fitted.

The grain of the iron should lie in the same direction as the lines of force, and where they are to leave the iron and pass out into the air, the grain should be on end.

Dynamos usually rest on cast iron bed plates; in "over-type" machines, *i.e.*, machines with poles upwards, the bed plate is usually made use of as a yoke, due attention being paid to the cross-section to allow for the variation in μ, if the limbs are of wrought iron. "Under-type" machines generally have a wrought iron yoke, even if limbs are of cast iron, in order to avoid top-heaviness. These machines must be magnetically insulated from the bed plate by a thick piece of brass, zinc, or other non-magnetic material.

It is, however, impossible by any device to avoid magnetising the bed plate to a certain extent, even though there be a thick plate of non-magnetic material between it and the field magnet. Some of the lines of force will, therefore, traverse the bed plate and be diverted from their intended purpose of passing through the armature. Machines are not generally constructed in this manner on this account, unless it is a matter of consideration to get the armature as low as possible.

Field Magnet Coils.

The field magnet coils must be thick enough to carry the maximum current for which this part of the machine is designed, without getting seriously heated. They must also have a sufficient number of turns to saturate the magnet when the machine is fully loaded. As it is not advisable to waste energy by introducing unnecessary resistance into the circuit, the coils should be made of copper of the best conductivity. They are generally insulated with cotton and shellac. With well shaped magnets of low magnetic resistance it does not appear to matter much where the coils are placed, it is, therefore, obvious that it is better to distribute the coils pretty evenly along the whole length than to heap them up at one or two points. The Victoria machine having a 4-pole divided circuit field magnet has eight coils. (Fig. 57, p. 62.)

Lord Kelvin states that in a series dynamo the resistance of the field magnet coils should be a little less than that of the armature, and that both should be small compared with the external resistance. In modern dynamos the tendency seems to be to reduce the resistance of both field magnets and armature as much as possible. His rule for a shunt machine is to make

$$R = \sqrt{r_s r_a},$$

when R, r_s, and r_a are the resistances of the external circuit, shunt, and armature respectively.

Further, to obtain a high efficiency, the resistance of the shunt coil should be 300 or 400 times as great as that of the armature. To obtain 90 per cent. efficiency, it should be at least 324 times as great.

A method of winding designed to meet the difficulties originally experienced in running more than one arc light in parallel off one dynamo, was devised by Major Cardew, R.E. This is no longer used in new dynamos for the service, but as some may be met with a description is necessary.

Cardew's method of winding consists of replacing the single series coil of the machine by as many parallel coils as there are lamps, into which it is required to divide the current. Each series coil is led to a separate terminal at one end, and to one of the brushes at the other end. The other brush is connected to a terminal. The machine is compounded as a short shunt machine. Victoria machines on this principle have hitherto been wound with four series coils for working four lights, but this subdivision into four only enables each lamp to be supplied with one-quarter the total current the machine is capable of producing, and this current is only sufficient to furnish a light of very moderate power, so that for search light purposes machines with two coils, for two lights, are found to be adequate to the requirements.

The principle upon which this method works is that of dividing the circuits to the separate lamps at the brushes, instead of at the terminals of the machine. This introduces into the separate circuits

the additional resistance of one of the series coils (·02 to ·03 ohms), and this, together with the resistance of the leads to the lamp, prevents the short circuiting of one lamp seriously affecting the others.

If these machines were compounded so as to give a constant difference of potential at the brushes, the independence of the lamps would be complete.

Each series coil need only be made of one-quarter the gauge necessary for a machine of equal out-put with only one series coil, since each coil only takes one-quarter of the total current, so that the cost of copper and bulk of the coils is no greater in these machines than in others.

CHAPTER V.

COMMUTATORS, BRUSHES, Etc.

Commutators.

The commutator of an ordinary armature, such as is used in the service, consists of a number of parallel bars of copper, or gun-metal, or phosphor bronze, arranged round the axle of the armature. They are insulated from the axle and from each other by layers of vulcanised fibre, mica, asbetos, or some other insulating material.

As the bars, or plates, are liable to be heated by imperfect contact, and corroded by sparking, and also are always being worn away by the friction of the brushes, they must be made of good stout strips of metal. Fig. 44 gives a section of a commutator, the black spaces representing the insulation between the copper bars.

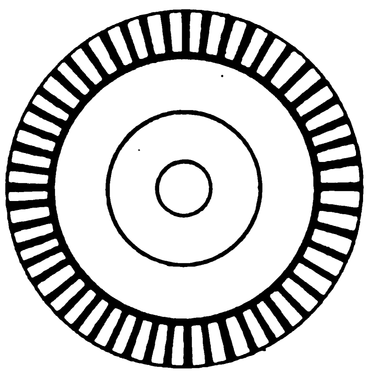


Fig. 44.

Brushes.

Service brushes are nowadays almost invariably made of copper gauze, wrapped up and sewn together in the requisite shape. Some older patterns may, however, be met with consisting of rows of copper (sometimes tinned) wires laid side by side and soldered together at one end, or of broad thin sheets of copper, slit at intervals, or of alternate layers of strips and wires. The most common size of gauze brush is 7″ × $1\frac{3}{4}$″ × $\frac{1}{4}$″, but of course this may vary with the load required and also with the number of brushes on the dynamo. The gauze is laid up square to the length of the brush; brushes laid up on the "bias" are difficult to file to shape and do not wear so well. The question of where the brushes are to be placed will be considered later.

A pattern of brush has been tried which is made of gauze impregnated with plumbago. This renders lubrication of the commutator unnecessary and produces a good surface on the commutator, but tends to heat it rather more than the ordinary brush.

Brush Holders.

Brush holders are of various patterns but generally speaking they should be made of good solid pieces of gun-metal, with slots for taking the brushes, B, and screws, S (Fig. 45), for clamping them in place. They must be insulated from each other and from the body of the machine. The brush holders are provided with springs Z to make the brushes press firmly but lightly on the commutator; if this pressure is too great the commutator will wear away into ruts, if it is too light the brushes are likely to jump and spark. The tension of the spring can be regulated by the nuts D D. The best pressure is one of about 2 lbs., measured where the end of the brush touches the commutator A. The brushes should rest on the commutator, making an angle of about 50° with the tangent;* if, however, the dynamo is to be run as a motor so as to rotate in either direction, the brushes must rest tangentially on the commutator, otherwise the wires will be bent and twisted when the

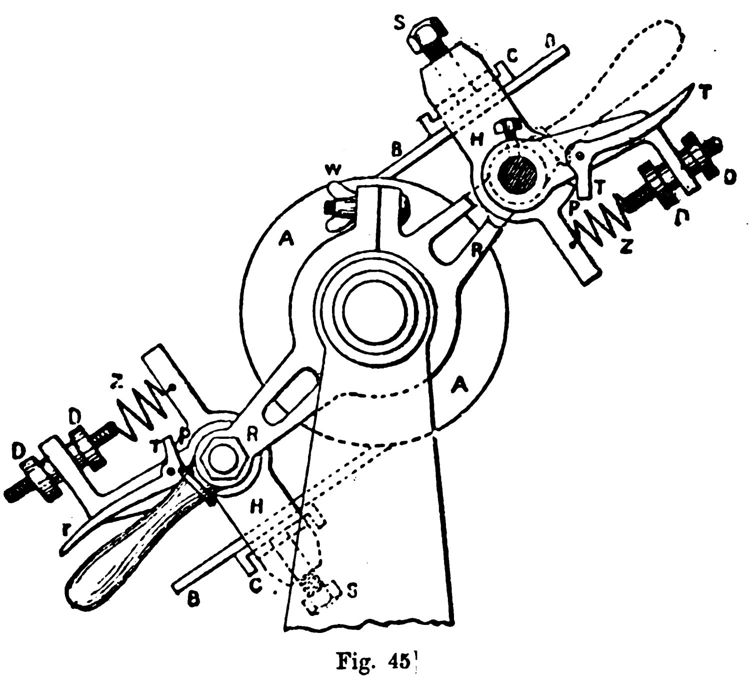


Fig. 45

* This does not apply to carbon brushes, largely used nowadays in motors, where the brush is practically radial.

machine is reversed. A light pointer is sometimes fixed to the brush holders; this is useful to show the attendant how much the brush is wearing away and how much it should be periodically fed forward. Two, or more, brush holders are generally placed side by side, so that the brushes may be re-adjusted or a fresh one put in without stopping the machine.

The brush holders are carried on a rocking lever R R, which can be clamped by the thumbscrew W in any desired position, as described on page 54, they are connected electrically with the proper terminals by means of flexible insulated leads, capable of carrying the full current of the dynamo.

The brushes can be lifted off the commutator and secured in that position by the catch T which engages in the projection P on the brush holder H. C C are metal plates intended to distribute the pressure of the screws S S evenly over the brushes, and to prevent damage to the brushes.

The above is taken as representing a general type only. The patterns of brush holders vary largely in small details, the general principles being, however, the same in all.

Position of Brushes.

On referring to Fig. 25, p. 21, it will be seen that when the rotation is right-handed, or the same as the direction of the movement of the hands of a watch, and the south pole of the field magnet on the left, and the north pole on the right, the induction in the armature tends to produce a current of electricity in both halves of the ring, from the bottom to the top, so as to make the upper portion of the armature core a north pole and the lower portion a south pole, in accordance with Ampere's well-known rule. The polarity in the ring will thus tend to oppose the rotation imparted to it, as by Lenz's law it ought to do. From what has been seen before, the potential at any point of the ring will depend upon the summation of all the E.M.F.'s induced in the various coils, and if we consider the negative brush in Fig. 25 as zero, the potential will rise in a regular manner round the armature, reaching its maximum value at the point diametrically opposite, and in order to realise the maximum current in the external circuit the brushes must be placed so as to touch the commutator at the points where the maximum difference of potential exists. If they were placed horizontally opposite to one another they would be at the same potential, and no current would result in the external circuit. The difference of potential between the brushes and the consequent external current will gradually diminish to zero, as the brushes are displaced from the position shown in Fig. 25 to that of horizontality.

Lead and Sparking at the Brushes.

Although at first sight it might seem that the proper position for the brushes is at the points where the neutral line of the field cuts the

commutator, or, in other words, at right angles to the line joining the poles of the field magnet, yet, practically, they have to be displaced from this position to another slightly forward in the direction of rotation. If this be not done, not only will they not be at the points of maximum difference of potential, but considerable sparking will take place between them and the commutator. This forward displacement is called the "lead," and is explained as follows:—

When any mass of iron is placed between the poles of a magnet it becomes magnetised. This naturally happens to the iron core of an armature, as shown in Fig. 46. Poles are developed at n_1

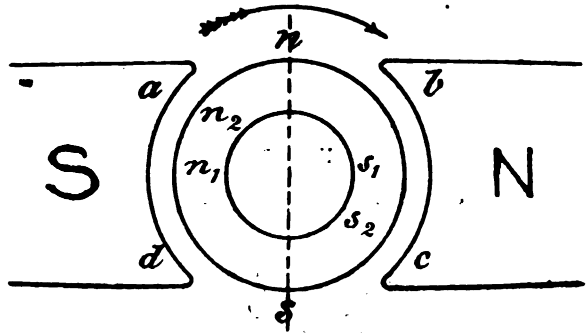


Fig. 46.

and s_1. When the armature is revolved this state of affairs is not altered, the iron alone revolves, the poles remaining stationary. When, however, a current passes through the armature coils a second magnetising force is brought to bear on the iron. It will be seen, in Fig. 26, that the current passes in opposite directions through the coils on the two halves of the ring, unites at the brushes. The effect of this is to magnetise the two halves in opposite directions, so that the ring becomes two semi-circular magnets placed north pole to north and south to south. Considering this magnetising force alone, we should have poles in the armature at the positions n and s shown by the vertical dotted line, which poles tend, by the laws of magnetism, to retard the rotation of the armature, n being attracted by S and repelled by N.

These two magnetising forces will produce (*vide* Fig. 46) resultant poles n_2 and s_2 somewhere between n and n_1 and s and s_1, their exact positions being determined by the relative strength of the magnetising forces. If the field magnet is very powerful in comparison with the magnetism produced in the armature by the current, the poles n_2 and s_2 will be very near to n_1 and s_1, and will approach nearer to n and s as the strength of the current in the armature coil increases; n_2 and s_2 also re-act on S and N, apparently dragging them round in the direction of rotation, Fig. 47. The result is that the most intense fields are not directly opposite the poles but rather forward in the direction of rotation, consequently so also

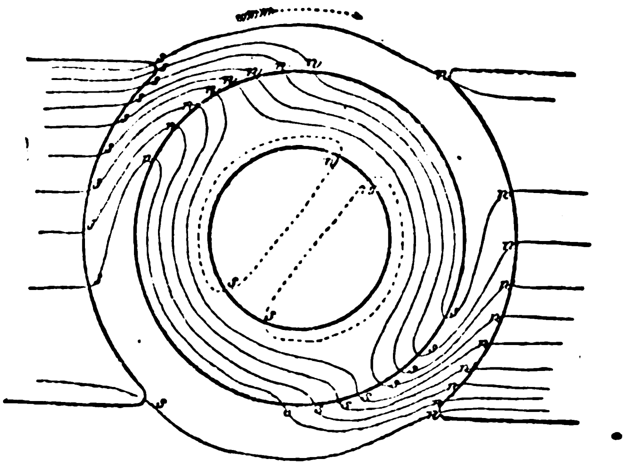


Fig. 47

are the neutral points, being at the ends of a diameter at right angles to the line joining the poles of the field magnets; the brushes must, therefore, be pushed forward to these points. This will have the effect of shifting *n* and *s* so that the real neutral points will be still further forward. As the movement of the brushes only slightly displaces n_2 and s_2, a point is soon reached at which no further forward movement is necessary. The distortion of the field and general lie of the lines of force is shown in Fig. 48 which is drawn from the pattern produced experimentally.

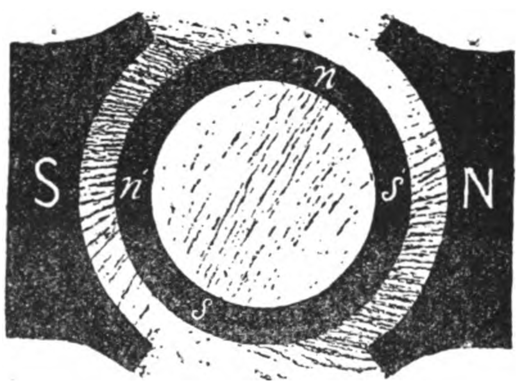


Fig. 48.

As above stated, the correct "lead," varies with the current the dynamo is generating, so that if a dynamo is to be used with different loads some arrangement must be made to enable the attendant to shift the brushes backwards or forwards as required; this is generally done by fixing the brush holders on a "rocker" concentric with the axis of the armature as shown in Fig. 45.

The arc is an unsteady load, and consequently the correct position of the brushes is constantly varying; it is, however, im-

possible to follow every slight change of load, and the brushes are fixed for as near the average load as possible. This is done by observing the position where the sparking between brushes and commutator is least.

A good dynamo should have very little lead, as then changes of load require only slight shifting of the brushes, or if the changes are only small, none at all; this is obtained by making the field magnet very powerful, so that the poles induced by it entirely overpower those produced by the current in the armature.

The sparking above referred to is chiefly caused by the brushes not being exactly at the proper points. The brushes must not break contact with one commutator plate before they touch the next, for otherwise the circuit will constantly be momentarily broken. The coil at the brush is therefore always short-circuited for an instant, and then immediately opened.

Now, it is on the state of affairs in this one coil momentarily undergoing short circuit that sparking depends, and it will be shown that the neutral points (*i.e.* the ends of the diameter at right-angles to the magnetic lines) are *not* the correct position for the brushes, but that the "axis of commutation" (*i.e.* the line joining the brushes) should be slightly *in advance* of the "neutral axis" already referred to.

Consider a portion of a ring armature, Fig. 49 (the action in a drum armature is identically the same, but not so easy to draw or

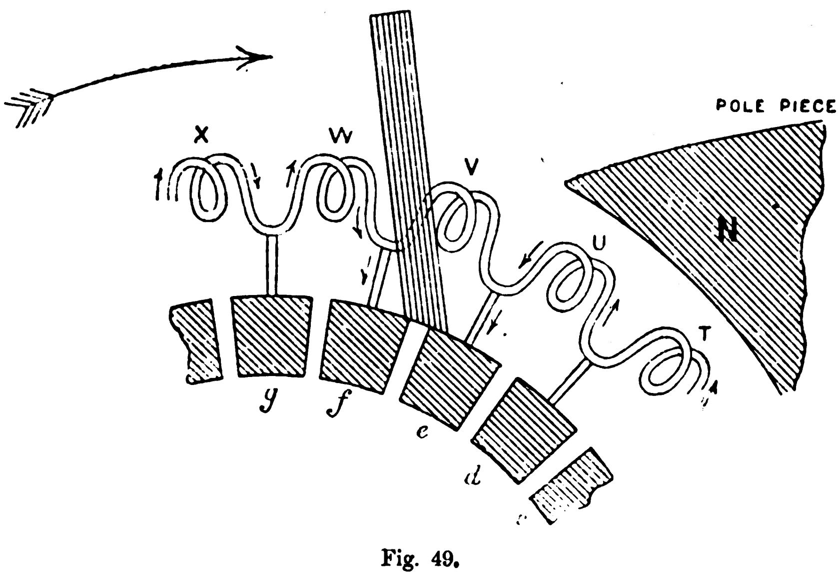


Fig. 49.

follow from a diagram). Now suppose the axis of commutation to coincide with the neutral axis, that is to say, when the idle coil is not cutting any of the magnetic lines, and therefore while short-circuited is not the seat of any electromotive force, then there will be no current in it, and as it emerges from under the brush

it will be thrown as a perfectly idle coil upon the right-hand half of the armature in which a current is flowing upwards towards the brush. Just before the bar *e* parts company from the brush, the current coming up through T and U is flowing through *e* to the brush, but as *e* moves away this current has suddenly to pass round coil V in order to get to the brush. But the current cannot suddenly rise to its full strength in coil V (the time is, of course, exceedingly short), and the result is that before V can get to work the current sparks across from *e* to the brush.

We have here supposed V to be a perfectly idle coil; let us suppose that it is not idle, but is actually still cutting magnetic lines, as would be the case if the brush had been shifted further to the left. Then during the moment of short circuit there will be an E.M.F. induced in the coil while under the brush. This may be small, but the short-circuited resistance will also be very small, and the current may therefore be large, and will have to be broken when *e* leaves the brush. Hence the sparking will be worse than if the coil were absolutely idle.

Now let us shift the brush the other way, *i.e.*, in advance of the neutral axis, so that as the coil passes under the brush it is beginning to cut the magnetic lines on the right. Then obviously there is being generated in it an E.M.F. tending to cause a current in the same direction as that in the right-hand half armature. Now, the ideal arrangement is that the brush be shifted so far in advance of the neutral axis that, during the time the coil is undergoing short circuit, there shall be generated in it a current equal in amount to and in the same direction as that current flowing in the right-hand half of the armature. When this is arranged there will be *no sparks*.

In some of the older dynamos the field under the leading horn was so weak that in order to comply with the foregoing conditions, the brush had to be so far advanced that several of the coils were in the right-hand half before one was arrived at in which the current was strong enough to cause sparkless commutation. The result of this was, of course, a considerable diminution in the voltage of the machine, as some of the coils were engaged in cutting the volts down. In a good modern dynamo, however, such a nice adjustment of the distribution of the field strength has been arrived at that the machine runs practically sparklessly at all loads.

Another cause of sparking is the roughness of the commutator or shakiness of the brush holder, which may cause the brushes to jump. All sparking should be carefully guarded against, as it is very detrimental to both commutator and brushes.

Bearings of Dynamos.

The bearings of dynamos are generally made of "white metal," cast round the shaft so that a perfect fit is secured. When the bearings have worn away and the shaft works loose, they can easily be re-cast. They must be kept well lubricated at first, but

when a machine has been in use some time very little oil is required. Rangoon oil is generally used in the Service, but, of course, there are various other kinds of oils which would do equally well. The oil is conveyed through a hole in the cap of the bearing from the lubricator, which consists of a glass or metal bottle or box, from which the oil is allowed to drop slowly. The lubricators in the Siemens dynamos are called "needle" lubricators. They consist of glass bottles inverted over the holes in the caps; a pin with a knob at the top closes the hole leading to the bearing, and prevents the oil running out when the dynamo is at rest, but when it is at work the jarring causes sufficient oil to run down into the bearing. The lubricators for the Victoria machines consist of iron boxes with one or more tubes through the bottom communicating with the bearings. Down each tube is passed a piece of copper wire, to the top of which some cotton-wick is attached, this dips into the oil; when the machine is worked the oil is drawn down the tubes to the bearings. This form of lubricator is not reliable nor can the supply of oil be regulated by them. The best form of lubricator is one in which the oil drips through an inverted cone with a hole at the apex; the supply is regulated by another cone inside the first, which can be screwed up or down so as to entirely cut off the supply or give the exact amount required, which can be seen through a hole or glass tube provided for the purpose. Such lubricators are popularly called "sight-feed" lubricators, vocabularised as lubricators, visible drop.

A form of lubricator now largely used is known as the oil-ring lubricator. In this lubricator one or more rings of larger internal diameter than the shaft ride loosely on the shaft, their lower portions dipping into an oil bath; as the shaft revolves the rings revolve with it, carrying oil to the bearings.

Driving the Dynamo.

The dynamo is driven by an engine either—

(1) Direct.
(2) By toothed gearing.
(3) By belting.

(1) The first method has been gradually introduced into the trade in proportion as high speed engines have become perfected. Ordinary engines are not as a rule adapted to high speeds, whereas a dynamo, unless very large, and therefore costly, for its maximum out-put, must be driven at high speed.

Turbo-generators, in which the moving parts are reduced to a minimum, and which have no reciprocating parts, are being introduced for direct dynamo driving. They are, however, somewhat wasteful of steam, except in the larger sizes (*e.g.*, 250 kw. and upwards) when worked "condensing."

A few high-speed reciprocating engines coupled direct to the dynamo have been introduced into the service. Such engines require, however, more care than the slower running engines.

In direct coupling, the power expended in driving belts and counter shafts is entirely saved, and space is greatly economised.

(2) The method of driving by toothed gearing was tried in the Service for a portable electric light equipment, in which a dynamo is mounted on a steam traction engine. It is rather noisy, but the noise is greatly reduced by the employment of vulcanised fibre for the teeth of the driving wheel, and of gun-metal for the pinion wheel; unfortunately this arrangement is mechanically weak. It is inconvenient for use except with the dynamo for which it has been specially designed. This arrangement is more suitable for outdoor work than belting, which slips and stretches in wet weather. It is, however, no longer used.

(3) Belting is generally used in the Service for indoor work; when used with intermediate shafting it is very convenient for working two or more machines, even at different speeds, as pulleys of different diameters can be used. A certain amount of work is, of course, expended in driving the shafting and in bending the belt. When driving a dynamo from a large pulley, or from a fly-wheel of an engine, care should be taken that the dynamo is not placed too close to the driving-wheel, for if it is the belt will not wrap round a sufficient portion of the dynamo pulley, and, unless so tight as to cause an excessive strain on the bearings, will slip under heavy loads. On the other hand, a very long belt is liable to sag, jump, and slip off the pulley. With a 5 feet 6 inches fly-wheel driving a 13½-inch pulley at 650 revolutions, 16 feet from centre to centre has been found to give good results. The underneath part of the belt should always, when possible, be the driving part. The slack part being uppermost, its sag tends to make the belt wrap further round the pulleys, while if the driving part is uppermost, the reverse effect is produced, and if a break occurs the ends of the belt are more liable to do damage. Belts are always liable to slip; this can be prevented to some extent by using powdered resin or syrups of various kinds. These are applied to the inner surface of the belt, and soon spread themselves over the entire surface, but should be used as sparingly as possible.

Belting may be made of leather links, or of ordinary single or double leather, laced or riveted. Hemp, cotton, canvas, and india-rubber, &c., cotton rope, chain belting, &c., are also sometimes used. In the Service leather belting (linked or solid) is generally used. The former is very convenient for jointing, and consequently runs very smoothly. In patching or lengthening link belting care must be taken to get the new portion with the same pitch from link to link as the old. Link belting is sometimes made with a flexible centre for smoother running. Canvas belting is frequently used abroad in situations where leather has been found to perish. The solid leather belting is, however, most generally used. Butt or lap joints, laced or riveted, may be employed, the former, of course, giving the smoothest running. In order to enable the belt to be tightened without unlacing it, the dynamo should be mounted on an under-frame, with screws for moving it away from the engine when required.

CHAPTER VI.

SERVICE DYNAMOS.

A list of the Service dynamos, with full particulars as to resistance of coils, &c., is given in Appendix II.

D_2 SIEMENS.

The first dynamo introduced into the Service was the D_2 Siemens shown in Fig. 50. A considerable number of these were originally issued to stations. They have nearly all been withdrawn, and the few remaining will probably be found to have been converted as explained below.

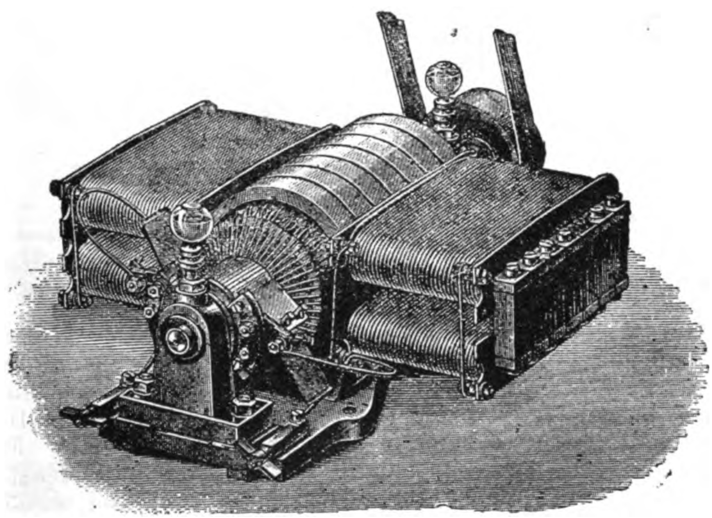


Fig. 50.

The core of the armature consists of a cylinder composed of iron wire wound on the axle to the requisite diameter, wire being employed to prevent eddy currents. Over the iron wire the sections of insulated copper are wound longitudinally, the ends of each section being attached to two neighbouring commutator plates; there are 56 sections and 56 plates in the commutator, each section being wound with two independent coils. The field magnet consists of two rows of soft iron bars (Fig. 51), arched

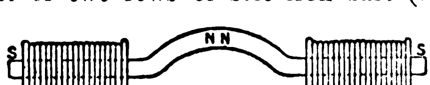


Fig. 51.

above and below the armature, and bolted together at the ends; the coils wound on brass bobbins fit over the cores. Fig. 52 shows the arrangement of the coils, by which it will be seen that these are four in series with the armature, two on either side.

SIEMENS' DYNAMO D_2.

The Leads shown dotted are the only ones that have to be disconnected when coupling two Machines for working in parallel.

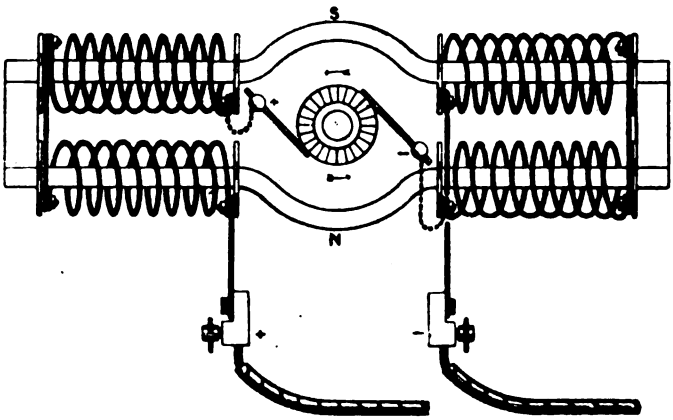


Fig. 52.

D_2 SIEMENS CONVERTED.

Most of the Siemens machines in the Service have been converted into compound wound machines on account of the inconvenience of working an arc with a series wound machine. One series coil on each side is removed to make room for the shunt coils. The arrangement is as shown in Fig. 53. The machine, as now compounded, has a rising characteristic giving about 66 volts at 700 revolutions at full load, *i.e.* 30 amperes, and 50 volts at the same speed on open circuit. To prevent this machine being over-run when used for arc lighting, a resistance at least ·3 ohms should be put in circuit with the lamp; part of this resistance will necessarily be provided in the leads, and the usual adjustable resistance of ·25 ohms should be used to furnish the rest. As 30 amperes gives but a poor light, two or four of these machines will generally be used in parallel as shown in Fig. 54, in which it will be seen that the positive brushes as well as the terminals are connected together. If is found that dynamos so connected give no trouble, as they regulate each other. The reason of this is that should one by any cause begin to go slower than the rest, its electromotive force will drop and the machine will consequently absorb less power. The power being thus unequally distributed, the slow machine will tend to race, while the faster ones will tend

D₂ SIEMENS' DYNAMO.

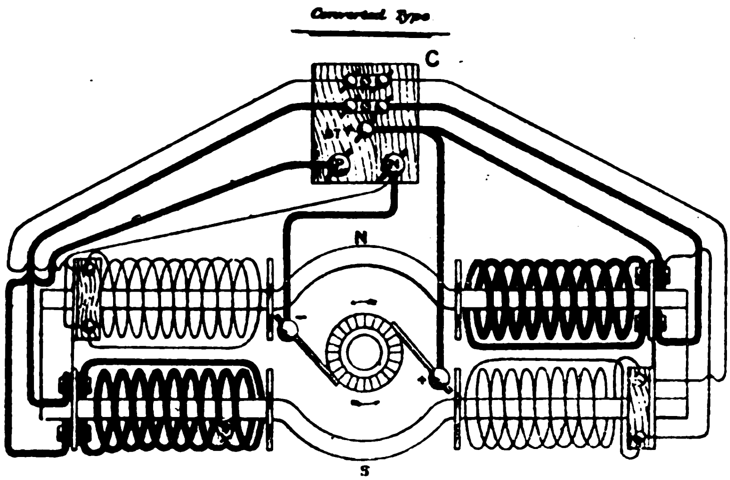


Fig. 53.

to slow down. The commutator board C (Fig. 53) is intended to facilitate the connections of machines in parallel.

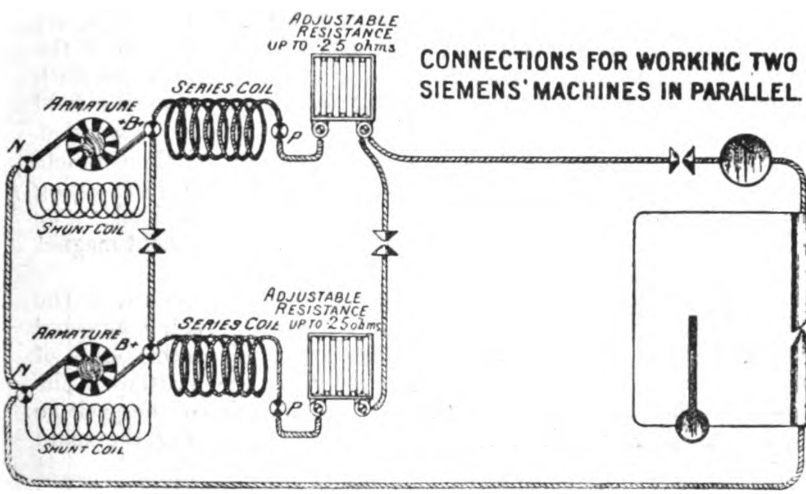


Fig. 54.

GRAMME.

Fig. 55 shows a Gramme machine, "A" pattern. A small number of D Gramme machines, similar in general construction to this, were purchased for the Service. The armature is a ring of an oblong section, wound with 112 coils, and having a 56-plate commutator at each end. Alternate coils are connected to opposite commutators, forming two complete windings entirely

'A' GRAMME.

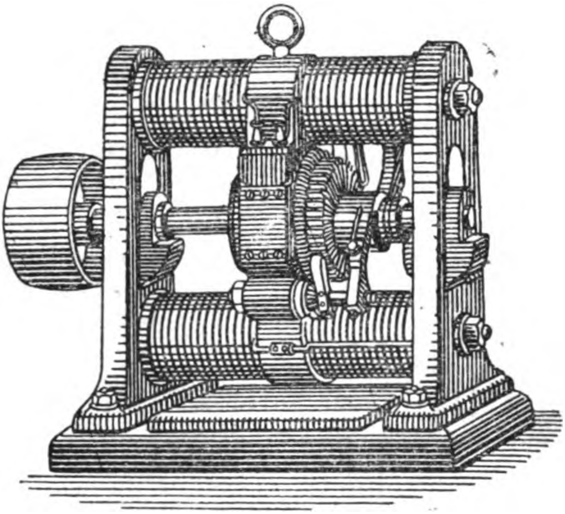


Fig. 55.

separate from each other; the four brushes are connected together in pairs, so the two coils work together in parallel. The field magnet is of the divided circuit type, with poles above and below the armature; it is wound with four series windings in divided with each other. The bearings are carried by the yokes of the field magnet, the necessity for separate supports being thus avoided. The brush holders are not very conveniently arranged, the contacts between brushes and commutator depending entirely on the spring in the brushes themselves. Fig. 56 gives front and back views of this dynamo, showing the connections between the field magnet coils, brushes, &c.

The copper strips, A B C D, are all connected by means of the piece E with the negative terminal. They are each connected to one of the ends of each of the series coils. The other ends of the series coils are all in connection with the upper brushes. The lower brushes are connected through the switch to the positive terminal. The switch is for the purpose of breaking the main circuit.

D. GRAMME.

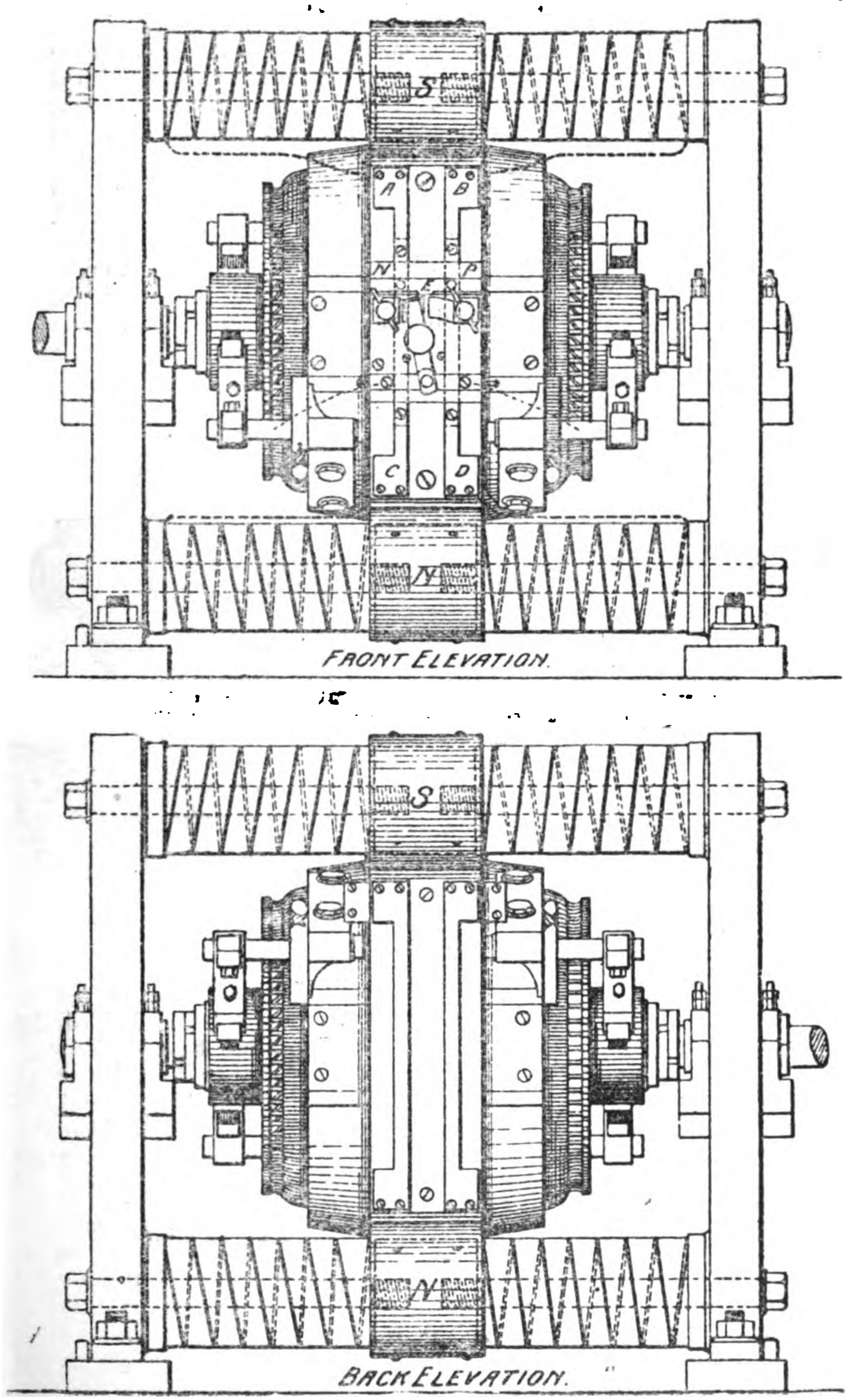


Fig. 56.

D_2 Victoria.

The Victoria, or Schuckert-Mordey dynamo (Fig. 57) has a disc-shaped ring armature (in the newest machines almost square in section), built up of layers of hoop-iron, separated by varnished paper to prevent eddy currents. It has a 60-plate commutator, and 60 coils wound on the armature. As it is a 4-pole machine, every opposite pair of commutator plates are connected across, so as to obviate the necessity for four brushes. The coils do not entirely cover the core, so good ventilation is obtained. The field magnet has four poles, and is of cast-iron, with suitable supports for the bearings, brush holders, and terminals cast on it. The winding is compounded to give 65 volts at the terminals, both on open circuit and at full load for a constant speed. The

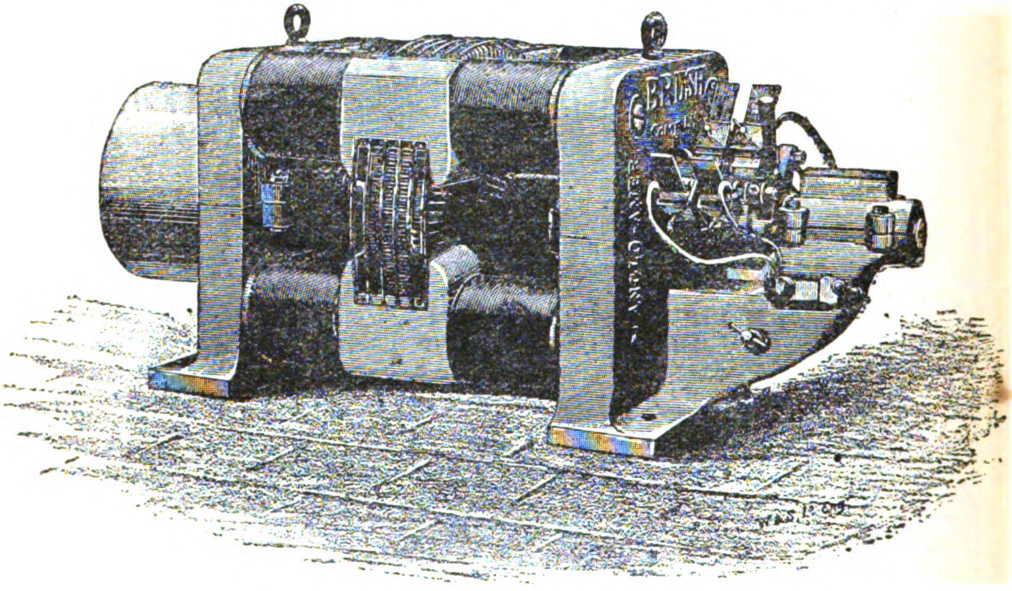


Fig. 57.

coils are wound in eight places, the series coils being under the shunt coils. The series coils consist of four coils in divided, wound side by side throughout, the ends coming to a divided plate on the switch-board, so that two, three, or four lights may be burnt in parallel, as explained on page 46. The general appearance of the machine is shown in Fig. 57. The brush holders are arranged on a rocker, and are provided with springs for keeping the pressure of the brushes equal; the brushes should, of course, be set at 15 commutator plates apart. There are two brushes on each spindle. The speed is about 650 revolutions per minute.

D_2 Victoria. S Type.

This type is rather more powerful, giving 70 volts 180 amperes at 810 revolutions. It has three bearings, but in general construction is similar to the regular D_2 pattern.

Latest Service Dynamo.

The latest type of machine in the Service is capable of furnishing 200 amperes at 80 volts. It has a level characteristic, and is practically sparkless at all loads.

Extracts from the Specification for this machine are given below :—

Extracts from Specification.

1. The dynamo to conform in all particulars to this Specification, and to be of the best material and workmanship throughout.

Type, Output, &c.

2. The dynamo to be of the two-pole type (poles uppermost), mounted on a substantial cast-iron bed, and constructed to give a continuous current of 200 amperes, and a difference of potential of 80 volts, at a speed not greater than 650 revolutions per minute. Each machine to be fitted with an over-hung pulley 11-inch face, and of such diameter as may be specified.

3. Two eye-bolts screwing into the pole-pieces to be provided for lifting the machine.

4. Suitable plugs to be provided to replace the eye-bolts when not in use. The machine to be constructed to revolve in a clockwise direction, when viewed from the pulley end.

5. A suitable under-frame, with all necessary holding down bolts and belt-tightening screws, to be provided. The belt-tightening screws to work in dogs, made to slide on the under-frame, and capable of being secured thereto by a clamping screw.

6. The frame to allow a movement of the machine of not less than 12 inches. The under side of the bed and the upper surface of the under-frame to be machined to a true surface. The distance apart of centres of holes in bed for holding down bolts to be 30 inches, measured parallel to axle.

Field Magnets.

7. The field magnet cores to be compound wound, with short shunt.

8. The characteristic of the machine is to be level, *i.e.* the potential difference at the main terminals under all conditions of load, within the capacity of the machine, is to be between 79 and 81 volts for constant speed, the speed maintained being that required to give a difference of potential of 80 volts at the terminals at full load. The machine to be self-exciting on open circuit.

9. The inside end of the shunt coil on each bobbin to be connected inside the coil to a heavy insulated flexible conductor of substantial section, so as to preclude any chance of failure to this portion of the machine.

Armature.

10. The armature is to be well secured to a forged steel shaft. The end of the shaft nearest the commutator to project beyond the bearing sufficiently to take a small pulley for driving a tachometer if required. The armature to be of the bar pattern. The winding to be of the drum type. The number of conductors to be 104. The conductors to be supported by means of driving studs, so that no movement of the conductors can take place irrespective of the direction of rotation of the machine.

11. The cylindrical surface of the completed armature to be true, and as regular as possible. The diameter over windings to be $12\frac{1}{2}$ inches.

12. The deviation from perfect form not to exceed $\frac{1}{16}$-inch at any point. The armature conductors to be tightly bound with tinned steel wire binders, of ample strength to resist the centrifugal force due to rotation.

13. The bindings to be arranged, as regards strength and position, so that a speed of a thousand revolutions per minute shall not injure them, or disturb any part of the armature winding.

14. The armature to be protected by suitable guards from injury while rotating, and to be correctly balanced, so that no appreciable vibration shall exist at normal speed.

Commutator and Brushes.

15. The commutator sections to be of phosphor bronze, or other suitable alloy, not less than $1\frac{1}{2}$-inch deep. The number of sections to be 52.

16. The commutator to be mounted on a gun-metal sleeve fitted on to the armature shaft.

17. The commutator sections to be held in place by collars on the sleeve, a closely fitted recessed joint being formed between the collars and the ends of the commutator segments. The sections to be formed with radial lugs of segmental section, forming a solid end to the commutator, and slotted to receive the armature connections.

18. The contact surface of the commutator to be not less than $6\frac{3}{4}$ inches long, and to be perfectly smooth and concentric with the axle.

19. The armature connections to be led to the commutator in such a manner that the diameter of commutation, when the machine is working on open circuit, shall be vertical.

20. Three brushes, in independent holders, to be fitted at each point of commutation. The brushes to be supplied with each machine. The width to accord with that of a standard gauge which will be issued on application.

PLATE I.

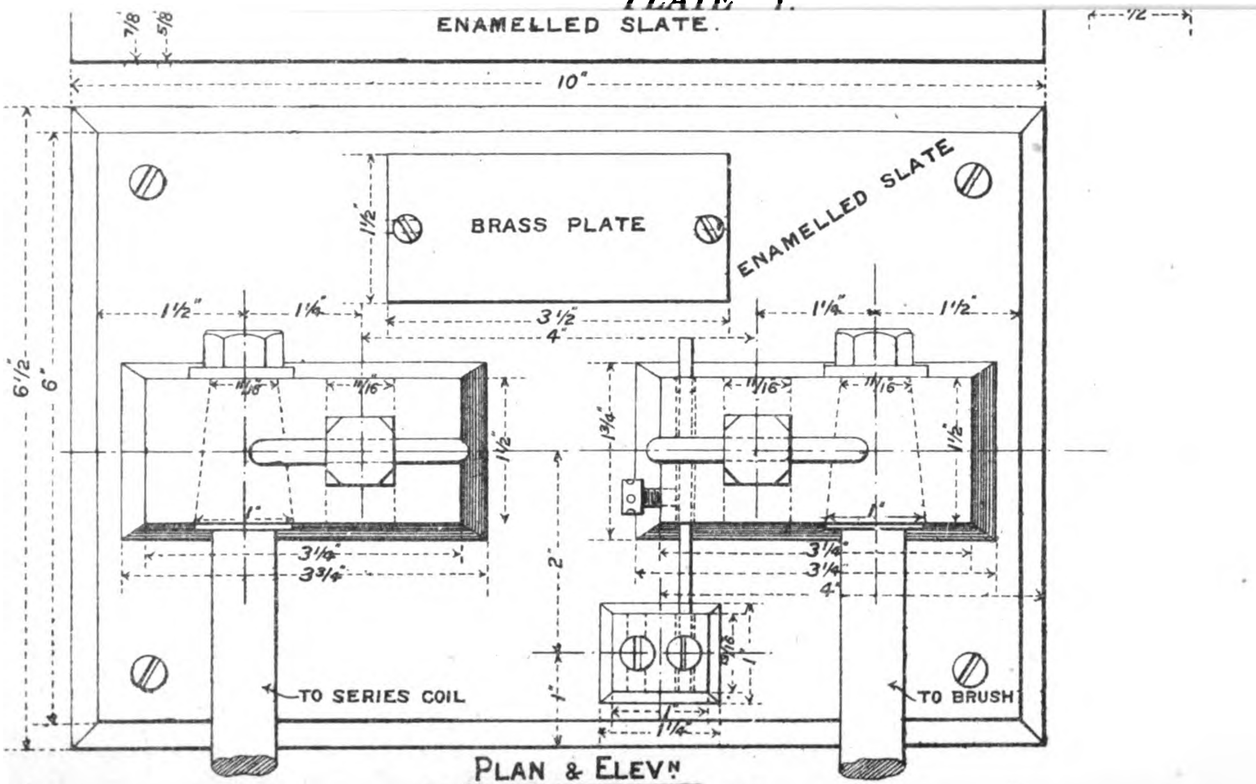


FIG. 2.

PLAN & ELEVN.
REAR TERMINAL BOARD.
1/2 FULL SIZE.

733.6.1906

E. Weller & Grahams, Ltd Litho London.

21. Each brush to be of the following dimensions: $7'' \times 1\frac{3}{4}'' \times \frac{1}{4}''$, and to be constructed in accordance with Specification R.E./254, which can be obtained on application to the Inspecting Officer, R.E. Stores, Royal Dockyard, Woolwich.

22. The brush holders to be of approved pattern, and to be provided with pointers, to facilitate the adjustment of their length, and also with pressure plates and hold-off catches. The amount of pressure of the brushes on the commutator to be effected by means of adjustable springs, the tension of which can be varied so that the pressure on the toe of the brush, measured normally to the commutator, is capable of variation between 0 lb. and $2\frac{1}{2}$ lbs. for each separate brush. The width of the holders measured internally to accord with a standard gauge which will be issued on application.

23. The whole of the brush holders must be mounted on a rocker, and must be arranged so that they can be reversed should it be desired to revolve the dynamo in the opposite direction.

24. The rocker and the flexible connections must allow of sufficient angular movement for this purpose, and also for the adjustment of the brushes under all conditions of load.

25. For any output the volts and amperes being varied independently between 40 and 80 volts, and 0 and 200 amperes respectively, it shall be possible to find a position for the brushes such that *no* sparking *at all* occurs.

Also when the brushes are set in the proper position for an output of 80 volts and 150 amperes, it shall be possible to vary the amperes between 75 and 200 *without causing any* sparking *at all*, the brushes remaining in the same position while the current is varied.

Also when the brushes are set in the proper position for 80 volts and any number of amperes up to 200, it shall be possible to reduce the amperes gradually to zero without producing appreciable sparking, the position of the brushes remaining fixed.

Terminals.

26. The main terminals of the machine are to be of the dimensions given in the drawing. A similar terminal is to be provided at the junction of the brush connection with the series coil.

27. The ends of the shunt coil are to be connected up by means of separate terminals, in such a way that they may be easily disconnected if required.

28. The clamping screws of the main terminals to be $\frac{1}{2}$-inch in diameter, rounded at the point, and of such length as to reach to the bottom of the hole in the terminal.

29. The head of each screw to be square, and to be provided with a stout pin, so that it may be used as a thumb screw. The arrangement of the terminals is to be as shown in the drawing.

Bearings.

30. The bearings to be of gun-metal of ample substance, and lined with white metal. Each gun-metal block to be properly fitted to the bed, or bearing caps.

31. Suitable lubricating channels to be cut in the inner surfaces of the bearings. The pulley bearing to be so mounted that the armature can be withdrawn without difficulty.

32. Suitable receptacles to be arranged, either in the bed or attached thereto, to catch all oil draining from the bearings, and to permit the same to be drawn off at will. Oil channels, drips, &c., to be arranged in such a manner that all oil running out of the bearings shall pass into the receptacles provided, and not find its way on to any other portion of the machine.

33. Lubricators of approved size and pattern to be provided. One or more for each bearing.

34. The lubricators to be Bailey's patent sight drop dial lubricator, of the dimensions detailed in Specification R.E./284, unless special sanction is obtained for the employment of another pattern of lubricator.

Insulation.

35. The insulation used throughout the machine to be of the highest quality, and to the entire satisfaction of the Inspecting Officer.

36. Mica insulation to be used in all cases between conductors which lie alongside or cross each other, and between which the full potential difference of the machine may exist.

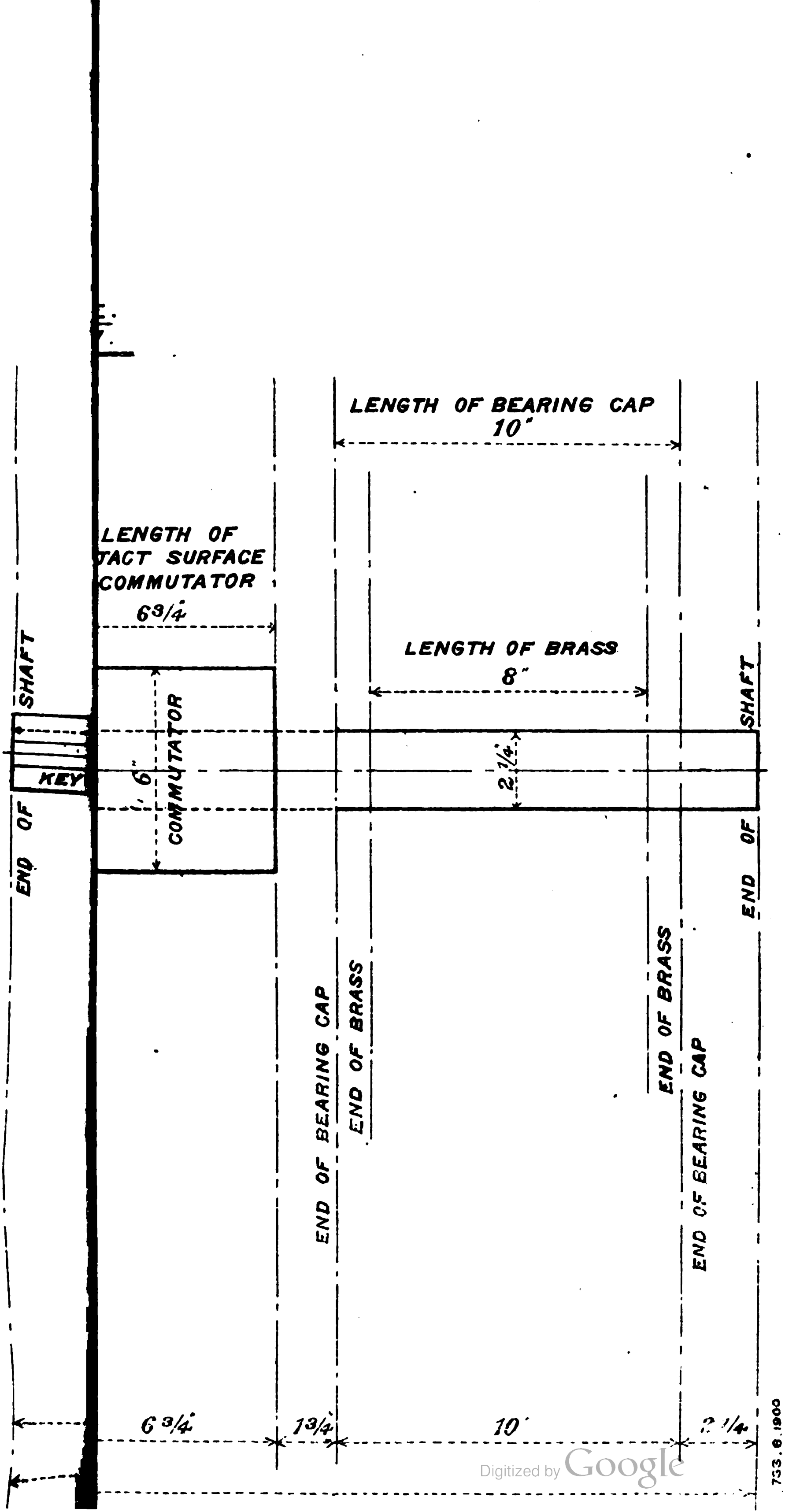
37. Mica insulation to be used between the armature conductors and binding wires.

38. The insulation between the commutator and sleeve, together with its collars, and also between the several sections and lugs of the commutator, to be of mica, and to be not less than 20 mils in thickness. The mica washers at the ends of the commutator segments to project $\frac{1}{8}$-inch above the surface of the commutator, and to be suitably supported with vulcanised fibre discs. The connections between the armature conductor and the commutator to be insulated by varnished tape or braiding throughout their length.

39. The armature core to be carefully insulated by means of layers of prepared tape coated with insulating varnish. The field magnet bobbins to be thoroughly insulated with varnished paper or other suitable material before the coils are wound upon them.

40. The inside ends of the field magnet coils to be carefully insulated where they are brought out from the bobbin. The whole surface of the armature conductors and the exterior surface of the field magnet coils to be thoroughly coated with a protective varnish, insoluble in water and oil, and of such a nature as not to become soft or brittle from the rise of temperature in the machine while under test.

41. The brush pillars to be insulated from the rocker by



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washers and bushes of vulcanised fibre, varnished with shellac. The size and shape of the washers to be such as to preclude any chance of leakage or short circuit across them from the deposition of copper dust. The insulation throughout to be capable of withstanding, without injury, a difference of potential of 400 volts continuous or 300 volts alternating between the dynamo frame and conducting wires, and also between the series and shunt coils.

42. The total insulation of the machine after the conclusion of the trial specified in paragraph 43 to be not less than 200,000 ohms.

Tests of Dynamo.

43. The machine will be tested by being run for six hours at full load (80 volts and 200 amperes).

44. The machine, either during the run or after the conclusion of it, must not attain in any part a temperature more than 60° Fahr. in excess of that of the surrounding atmosphere. The measurement of rise of temperature will be taken either by thermometer or by increase of resistance of the conducting wires, at the option of the Inspecting Officer.

45. The electrical efficiency must not be less than 90 per cent., and the efficiency of conversion not less than 85 per cent.

Engraving.

46. The following information is to be given on each machine in a conspicuous manner either cast thereon, or cast or engraved on a metal plate or plates attached thereto:—

Name of manufacturer.
Year of supply.
Weight of machine, exclusive of under-frame.
Maximum current (200 amperes).
Volts at terminals (80).
Revolutions required per minute to maintain 80 volts at full load.
Position of axis of commutation.
Maker's number for future reference.

Workmanship and Materials.

47. All workmanship and materials to be of the very best.

48. All cast-iron employed in any part of the machine or under frame to be of tough grey cast-iron, sound and free from flaws.

49. The field magnet cores to be of the best wrought-iron, or magnetic steel, except yoke, which may be of cast-iron, if desired.

50. All joints in magnet cores to be carefully faced, and securely bolted together.

51. The armature core to be of the finest magnetic iron, properly annealed, laminated, and insulated. The thickness of the sheets used for the armature core not to exceed No. 24 S.W.G. The forged steel armature shaft to be free from flaws of every description.

52. All gun-metal and brass castings to be perfectly sound.

53. The gun-metal to contain not less than 12 per cent. of tin in its composition.

54. The metal of the commutator to be dense and tough, of uniform hardness throughout, and free from all imperfections. All brass screws to be of hard rolled or drawn metal. The copper used for the conductors and connections to have a conductivity not less than 98 per cent. of that of pure copper, to be of the finest quality, and perfectly annealed.

55. The armature conductors to be stranded and constructed in such a way as to avoid eddy currents.

56. Each separate wire of the stranded conductors or shunt coil winding to be capable of bearing an extension of 10 per cent. without breaking.

57. No flux for soldering except resin, is to be used in any part of the machine.

58. All screws are to be full threaded, and to fit without shake. Ordinary threads are to be Whitworth standard.

59. Similar parts of all machines made to this Specification by any one Contractor are to be constructed to gauge, so as to be interchangeable. Spare parts, whether ordered with the machines or subsequently, are to be similarly constructed. The dimensions of the armature, commutator, and shaft are to agree with the drawing, so that armatures made by different makers to this Specification shall be interchangeable.

CHAPTER VII.

MANAGEMENT OF DYNAMOS.

Faults in Dynamos. Their Causes, Effects, and Localisation.

Faults in dynamos are referred to below in the order in which they are likely to occur under service conditions, other than failure to excite, which is dealt with later.

I.—*Electrical faults.*

(i) *Sparking at brushes;* the causes and prevention of which are dealt with under the chapter on commutation.

Whenever sparking takes place the dynamo is not working under its best conditions, and the brushes and commutator are liable to injury.

(ii) *Failure to excite* from loss of magnetism is dealt with later, but may also be caused by—

(*a*) Disconnection or short circuit in shunt coil;

(*b*) Disconnection in armature coils, or short circuit in armature; or no contact between brush and commutator.

(iii) Dynamo not giving its full volts on open circuit at proper speed, owing to—

(*a*) Partial short circuit, perhaps due to contact between series and shunt coils, or high resistance in shunt coil;

(*b*) Short circuit in armature coils.

(iv) Volts at terminals of a properly compounded dynamo decreasing with increase of load, due to a short circuit in series coil; or to the series coil being connected the wrong way round.

(v) Bad insulation between field magnet coils and body of machine, owing to careless workmanship or to the insulation being rubbed off. This fault is generally to be found where the ends of the coils or sections are brought out. The result would be a loss of volts if the fault be in more than one part or coil of the dynamo, or if there be a leak in the external circuit. Injury to the machine may easily result.

II.—*Mechanical faults.*

(i) *Heating of bearings* due to want of proper lubrication or to the dynamo not being properly set up.

(ii) *Belt slipping* or jumping off. Apply resin or other suitable materials, or tighten the belt by screwing back the dynamo. See that the dynamo pulley is carefully lined up with the driving wheel.

(iii) *Armature coils rubbing against pole-piece*, owing to—

(*a*) The wearing away of the bearings, perhaps due to the dynamo being badly set up; these must be refitted;

(*b*) A want of rigidity in narrow ring armatures, the attraction between the field magnets and armature core causing the coils to rub against the pole-pieces, thus cutting the insulation and short circuiting the armature through the body.

(iv) *Heating of coils*, owing to bad ventilation. The normal output should never be exceeded.

Localisation of Faults.

1. By rough tests of conductivity and insulation with a 3-coil galvanometer and two or three Leclanché cells.

Disconnect the brushes from the field magnet coils, the ends of the shunt and series coils from each other, and raise the brushes off the commutator.

Then for continuity tests of—

(*a*) *The armature.*—Plug the low resistance coil of the galvanometer, connect it up to the battery and note deflection obtained on short circuit; then hold the ends of the leads on the segments of the commutator approximately where the brushes would rest, and turn the armature slowly by hand until all the segments have passed under the leads. The deflection obtained should be practically equal to that obtained on short circuit. If one of the radial connecting strips were disconnected from its segment or from the armature winding, the deflection would go off while the disconnected segment remained under either of the testing leads. A disconnection in one of the coils cannot be localised in this manner when the armature is of very low resistance; under such circumstances, more elaborate instruments must be used.

(*b*) *Brush connections.*—Hold one lead on to the end of the brush lead and the other to the tip of the brush or parts of the brush. The deflection obtained should be as at (*a*). The fault likely to occur is dirty contact owing chiefly to the proximity of the bearing lubricator.

(*c*) *Series coils.*—Hold the leads on to the two ends of the coil, the deflection obtained should be as in (*a*).

(*d*) *Shunt coil.*—Plug 10-ohm coil of galvanometer.

A good deflection should be obtained.

If a rough idea of its resistance be required, it may be found by substitution, that is, by using the same leads, galvanometer and battery connected up to a box of coils; adjust the resistance in the box until the deflection obtained through the shunt coil is reproduced, the resistance unplugged will be the approximate resistance of the shunt coil.

For insulation tests:—

Plug the high resistance coil of the galvanometer.

If the insulation be perfect, no deflection will be obtained.

Should any appreciable deflection be obtained, the resistance of the fault may be approximately determined as in (*d*) above.

For insulation tests of :—

(*a*) *Armature.*—Hold one lead on to any part of the commutator and the other on the spindle.

(*b*) *Brush holders and body of dynamo.*—One lead on to a clean spot on the body of the machine, and the other to each of the brush holders in turn.

(*c*) *Brush holders with each other.*—One lead on each brush holder.

(*d*) *Series coil and body of dynamo.*—One lead on to one end of the series coil, the other on to a clean spot scraped on either pole-piece.

(*e*) *Series and shunt coil.*—The leads on to one end of each coil.

(*f*) *Shunt coil and body of dynamo.*—One lead on end of shunt coil, the other to pole-piece.

The faults (*b*) and (*c*) usually occur through a want of cleanliness. The metallic dust from the commutator is apt to bridge over the insulation between the brush holders and the body of the machine. The insulation should be kept quite clean and free from oil.

II. For testing and localising faults with Wheatstone's bridge and sensitive reflecting galvanometer, always use leads of a low resistance compared with the part to be tested or the result will be of only approximate accuracy. In any case the resistance of the leads should be accurately determined and allowed for.

When testing very low resistances, care must be taken not to heat the resistances in the box of coils; to prevent this a resistance of 100 or 200 ohms should be placed in the battery circuit.

The tests should be taken in the order detailed in I, clean, tight, and well insulated connections being a most important feature.

III. *To test the insulation of the field magnet coils while the dynamo is running.*—Plug the high resistance coil of a 3-coil galvanometer. Connect leads to its terminals of sufficient length to allow of its being placed outside the range of the magnetism of the dynamo.

Hold one lead on to the pole-piece, and momentarily touch the other on to each of the dynamo terminals in succession. If any appreciable deflection be obtained the fault must be localised.

The dynamo must, of course, be run either on open circuit or with a well insulated external circuit when the test is made.

IV. *To test the conductivity resistance of the series coil while the dynamo is running.*—With a voltmeter, measure the volts at the brushes and the volts at the terminals, and note the current in the external circuit; then

$$\text{R of series coil} = \frac{\text{volts at brushes} - \text{volts at terminals}}{\text{C}}$$

V. *Running the dynamo to localise short circuits in*—

(*a*) *The armature.*—Run the dynamo on open circuit at full

volts for five minutes, then stop the engine and turn the armature by hand, feeling each coil as it passes.

The *warm* coils will be the short circuited ones.

(*b*) *Series coil.*—Run the dynamo at 10 per cent. in excess of its normal current for about 15 minutes. The short circuited coils would be cool, while the others would be rather warm.

(*c*) *Shunt coil.*—Run dynamo on open circuit at full volts for about 15 minutes and localise as in (*b*).

To Excite a Dynamo.

A dynamo may fail to excite from such faults in the coils as have been previously mentioned, but it may sometimes happen that a dynamo has lost its residual magnetism to such an extent as to render it unable to excite without assistance.

This occurs, as a rule, in cases in which—

(*a*) The field magnets are constructed wholly of wrought-iron and the machine is seldom used;

(*b*) The direction of rotation has been reversed without reversing the brush connections;

(*c*) The position of the brushes or brush connections have been reversed, thus establishing a small current through the field magnet coils, tending to demagnetise instead of "building up."

To Excite a Short Shunt Compound Dynamo.*

1. Place the brushes on what are considered to be the neutral points, but in all the tests the brushes must be moved by means of the rocker to different positions on the commutator, allowing them to rest for 2 or 3 minutes at each point (because in some dynamos the ends of the coils are not brought straight out to the commutator, but twisted in such a manner as to bring the brushes into a convenient position). Run the dynamo at its normal speed on open circuit for about 5 minutes. Should this fail, reverse the shunt coil, connect it to the brushes and try again. Should this fail, restore the original condition and join the terminals with a piece of copper wire, which will fuse at a current not exceeding the normal output of the dynamo.

Should this fail—

2. Reverse the brush connections, leaving the terminals connected by the fine wire as before, and, if necessary, move the brushes as before.

Should this fail—

3. Disconnect the shunt coil from the brushes and on to it connect another dynamo, or some secondary cells or other source of E.M.F. with an adjustable resistance, the positive terminal of which must be connected to that end of the shunt coil which it is intended to connect to the positive brush.

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* In a long-shunt machine the procedure will differ a little from that given. A short consideration should suffice to show in what particulars.

Pass a current in this manner through the shunt coil for 2 or 3 minutes (being careful to break it gradually), then re-establish the dynamo connections, when the machine should excite. If it fails the operations described must be gone through again.

In the above tests the possibility of the series and shunt coils opposing each other has not been considered, as it is a contingency unlikely to occur.

Reversing the Polarity of a Dynamo.

When a dynamo is to be run by itself it does not matter in the least what its polarity is as far as the dynamo itself is concerned, but when two or more compound dynamos are to be run in parallel, it is necessary that the brushes which are connected to the series coils should be of the same polarity; also, when a dynamo has a polarity permanently marked on it, it is desirable to adhere to this to prevent mistakes.

Dynamos sometimes have their polarity reversed during the process of charging accumulators or when two or more are run carelessly in parallel.

To Reverse the Polarity of a Compound Dynamo.

As in the case of exciting a dynamo, disconnect its shunt coil and apply a source of power to the ends of the shunt, so that the current is in the reverse direction to that in which it originally went. Keep the current on for 3 or 4 minutes, then on re-establishing the connections the machine will be found to be reversed in polarity.

To Reverse the Direction of Rotation of a Dynamo.

1. Reverse the position of the brush holders on their spindles and by means of the rocker shift them back so as to allow the brushes to rest in their proper positions on the commutator.
2. Reverse the brush connections.

[N.B.—In a 4-pole machine, with brushes at 90°, it will generally be found unnecessary to reverse the connections, as, when the brush holders have been reversed, the rocker can generally be rocked *forward* sufficiently to allow the brushes to change their neutral points.]

Instructions for N.C.O. or Man in Charge of Dynamo.

1. Before starting the dynamo, see that all connections are clean, bright, and properly insulated from each other, and that the leads are large enough to carry the required current.
2. See that the commutator is clean, that there is no dirt

between the radial and connecting strips, and that there is nothing likely to foul the armature.

3. See that the brushes are properly set. Before fixing the brushes in their holders they must be carefully trimmed and bevelled to the proper angle.

For this purpose a clamp is provided (Fig. 58) consisting of a trough and pressure plate of wrought iron with a bridge clamp and screw for tightening.

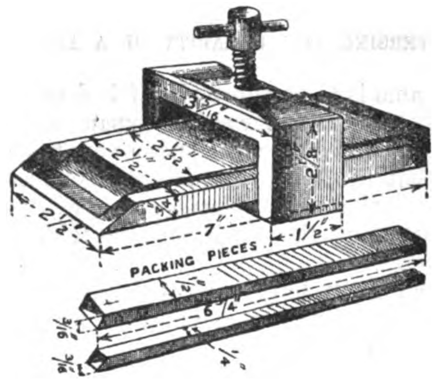

Fig. 58.

The bevelled facets of the trough and clamp are case hardened. The brushes are clamped between these pieces and the ends filed off smooth.

Should one of these clamps not be procurable the following makeshift may be used:—

Carefully tie a piece of smooth emery paper round the commutator, being sure that it lies evenly. Then having inserted the brushes in the brush holders, turn the armature slowly (preferably by hand) and gently press the brushes on until the ends are ground to the shape required. This if very carefully done will make a good seat on the brush.

The greatest wear and tear on the machine takes place at the brushes and commutator, and it is of the greatest importance that they receive careful attention. The machine will not give any better results by pressing the brushes hard on the commutator, and the effect will be additional wear. With proper care the commutator should soon acquire a dark burnished surface which shows that it is properly attended to, but which is not easy to obtain with a varying load such as large arc lights.

When the work comes on the brushes must be carefully adjusted by means of the rocker to the position of least sparking.

4. See that the lubricating arrangements work satisfactorily.

5. Care should be taken that the brushes are fed forward occasionally to make up for wear.

6. The even wearing of the commutator is much promoted in broad ring or drum armatures by lining up the machine so carefully that the armature spindle can travel backwards and forwards

in its bearing as it runs. End play is often allowed for this purpose.

7. The commutator should be cleaned before each run, and may while running be occasionally wiped over with a piece of clean rag (not waste) on which is a very small quantity of vaseline.

8. Should the commutator become at all rough, it should be smoothed with a smooth file well chalked, followed by emery cloth well oiled, and finished with very fine emery cloth used dry. This must only be done with the brushes removed and the machine revolving slowly, preferably turned by hand.

9. If there are two or more brushes side by side they may be raised or removed one at a time for purposes of adjustment, but the greatest care must be taken never to break the circuit by lifting a complete brush off the commutator while the machine is running.

10. If for any reason it be found necessary to take the field magnets apart, great care should be used in putting them together again, to wipe all iron faces perfectly clean, and to screw them firmly into contact, all electrical connections being made exactly as they were before dismantling.

11. When through wear or damage it becomes necessary to true the commutator up in a lathe, the following precautions should be observed:—

(*a*) Before starting make sure that no part of the armature will come in contact with any part of the lathe, saddle, or slide rest in any part of its travel.

(*b*) Use a fairly fine pointed tool, with considerable top rake (such as is used for turning steel), and take a light cut with slow feed. If too wide a tool be used the copper will be dragged over the insulation.

In any case when the turning and polishing is complete the separate strips should be carefully examined and any copper bridging the insulation must be scraped off.

(*c*) When the armature has been replaced, test it for short circuits by running on open circuit as described previously.

12. When moving an armature, if it be necessary to put it down, be careful that it does not rest on its winding. Wooden blocks should be used and the armature supported on them by its spindle.

CHAPTER VIII.

MOTORS.

An electro-motor is the converse of a dynamo or generator, *i.e.* it is a machine for converting electrical into mechanical energy Any continuous current generator can be used as a motor, the armature being made to rotate by passing a current through it from an external source, while the field magnets are excited.

Two points are vital to the right understanding of the action of electric motors: (i) the propelling pull: and (ii) the counter electro-motive force.

The first point is that the force which produces the rotation is the pull that the magnetic field exerts upon the wires carrying the current; the second is that the armature as it revolves generates a counter E.M.F. as its wires cut the magnetic lines.

As regards (i) in a generator this pull on the wires retards the motion and from it, in fact, arises the need for the work that has to be done by the engine in driving the generator. In a motor this is the propelling force.

As regards (ii) consider two similar machines (Fig. 59) one acting as a generator, the other as a motor with their connections between brushes and field magnets so arranged that they run in the same direction.

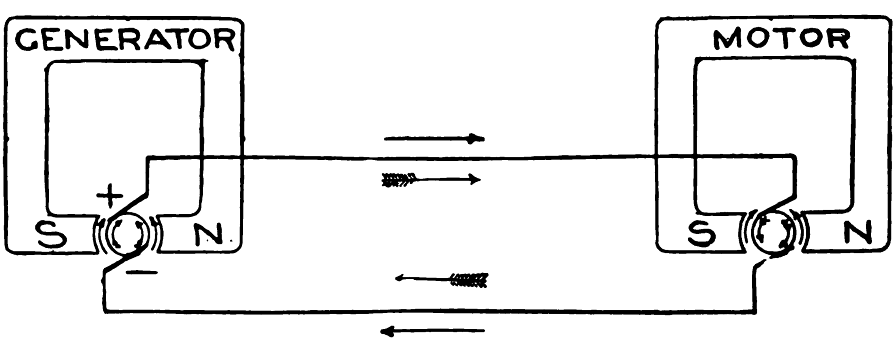

Fig. 59.

Each is rotating right-handedly and (as shown by the plain arrows) they each generate an E.M.F. tending upwards from lower brush to higher, but in the case of the generator this is in the same direction as the current (shown by the *fléched* arrows), in the case of the motor it opposes the current.

In a generator, directly we begin to put a load on we feel a "*counter mechanical force*" acting against us. Similarly in a motor we find an opposing reaction, which is a *counter electromotive force.*

As regards the theory of electric motive power, it can be shown mathematically that the efficiency with which a perfect motor utilises the electrical energy supplied to it depends upon the ratio between this counter E.M.F. and the impressed E.M.F. Of course, no motor can utilise all the energy, as we cannot construct machines devoid of resistance, and, therefore, part of the current is wasted in heat, putting aside the question of friction, &c.

Let W stand for the power supplied to the motor by a battery or generator of some sort, and let w stand for that part of the energy utilised in mechanical work by the motor. (These symbols may stand for the number of watts supplied and utilised.) All that is not utilised will be wasted in heating the resistances; the heat loss will therefore be $W - w$.

Now, if we want our motor to work under economical conditions, we must have as little heat waste as possible, *i.e.* w must be as nearly as possible equal to W.

Let E be the E.M.F. with which the battery supplies the motor, and let us call the counter E.M.F. e.

Then if the motor be prevented from turning, we have

$$C = \frac{E}{R},$$

and when the motor is running, the resistances being constant,

$$C = \frac{E - e}{R},$$

now, if C be the current flowing, the whole electric power W expended in unit time will be expressed in watts

$$W = E\,C \text{ at any time, or when the motor is running } = E\left(\frac{E - e}{R}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

When the motor is running, part of this power is being spent in doing mechanical work and the remainder in heating the circuit; the useful part may be written down as the product of the armature's own volts (the counter E.M.F.) and the amperes, or

$$\text{(useful watts) } w = e\,C = e\left(\frac{E - e}{R}\right) \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

or $W = w +$ watts lost in heat; but heat loss $= C^2R$, $\therefore W = w + C^2R$.

Comparing (ii) with (i) we get

$$\frac{w}{W} = \frac{e}{E}\left(\frac{E - e}{E - e}\right) = \frac{e}{E} \quad . \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

This is the law of efficiency, and the equation shows that we may make the efficiency as nearly 100 per cent. as we please by so adjusting the speed that e is nearly equal to E

Now the power utilised is equal to the difference between that supplied and that wasted in heat, or

$$w = \mathrm{E\,C} - \mathrm{C^2R}$$

to find the maximum value of w for a given value of E we must use the calculus and equate the first differential coefficient to 0, then

$$\frac{dw}{d\mathrm{C}} = \mathrm{E} - 2\,\mathrm{C\,R} = 0 \text{ or } \mathrm{C} = \tfrac{1}{2}\frac{\mathrm{E}}{\mathrm{R}}$$

i.e. to get maximum rate of working out of the motor, the motor must run at such a speed as to bring the current down to half the value it would have if the motor were held at rest.

The efficiency of the motor when working at this maximum rate may be found from

$$\mathrm{C} = \tfrac{1}{2}\frac{\mathrm{E}}{\mathrm{R}} = \frac{\mathrm{E} - e}{\mathrm{R}},$$

or $$\frac{e}{\mathrm{E}} = \tfrac{1}{2}$$

or $$\frac{w}{\mathrm{W}} = \tfrac{1}{2}$$

i.e. the efficiency is only 50 per cent. when the motor is doing its work at maximum rate.

This must not be taken to mean that a motor cannot work at more than 50 per cent. efficiency; on the contrary, if we have a motor capable of doing far more work than the task required of it, it will be working when at this task at considerably over 50 per cent. efficiency; how far this may be carried would depend on initial outlay, interest on capital, &c., &c.

Another way of putting it is, that with any given motor the less work it is doing at any time, the more economically is it working until, when the work decreases to zero, the motor is working at 100 per cent. efficiency!

As has been previously stated, any good dynamo will run as a motor and the conditions governing the design of motors (such as cross-section of iron, reluctance, &c.) are practically the same as for generators. In the first chapter was given a rule for determining the direction of current in a generator, when we knew the direction of magnetic flow and the direction of rotation. There is an analogous rule for determining the direction of rotation in a motor when we know the direction of magnetic flow and the direction of current flow, only in this case the *left* hand must be used and we get the *left hand rule* (Fig. 60).

Hold the thumb, first finger and remaining fingers of the left hand at right angles to one another. Then if the thumb be laid along the conductor in the direction in which the current is flowing, and the remaining fingers point in the direction of the

lines of force (*i.e* from N to S) the conductor will be urged in the direction of the first finger.

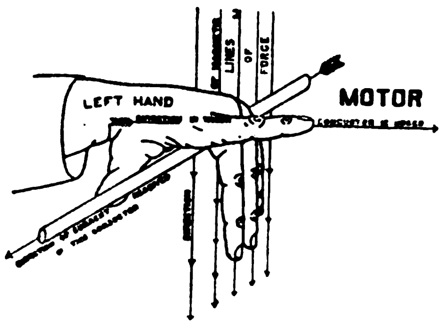

Fig. 60.

As regards the suitability of the various types of generators for use as motors, we may take them shortly in succession and consider their points.

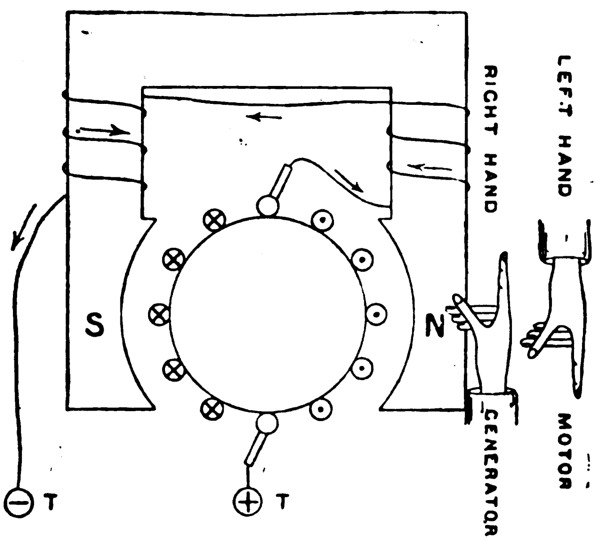

Fig. 61.

(*a*) *Series Dynamo.*—By a consideration of the diagram we see by the right and left hand rules that with a series dynamo it is immaterial in which direction we impress an E.M.F. The machine will in either case run in the same direction, and in a contrary direction to that in which it ran as a generator. The dots and crosses are conventionally used as representing the point and *flèche* of an arrow and thus indicating the direction of the current.

A further consideration will show that although above a

certain speed this motor will take very little power (since the counter E.M.F. is nearly as great as the impressed E.M.F.), yet it can never develop a counter E.M.F. equal to the impressed

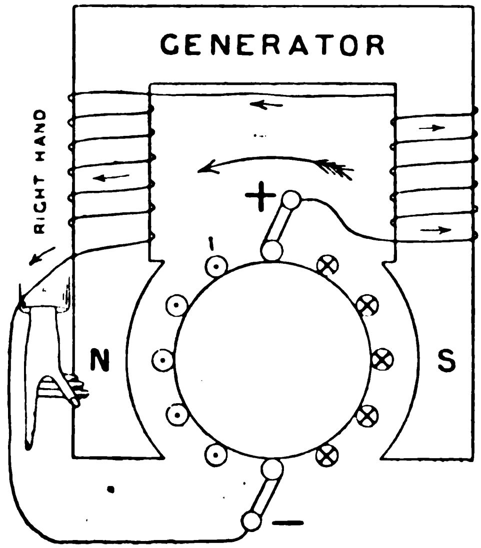

Fig 62.

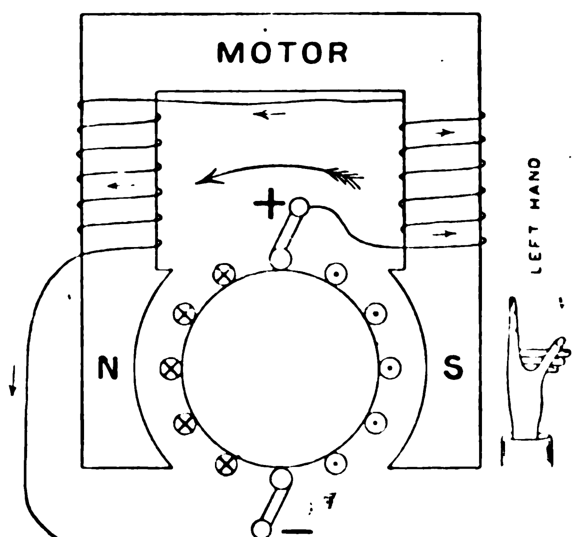

Fig. 63

E.M.F. Nor will it *give out* any electrical power, because before it could do so its field magnets would have to be reversed in polarity,

passing through a zero point of absolute non-magnetism. For this reason this machine is not very suitable in places where it could attain a dangerous speed; its great torque at starting (when the current through field magnet winding and armature is a maximum) makes it particularly suitable for certain classes of work, and on this account this type of motor is largely used on tramcars, &c. (which have sometimes to start up a hill or on a curve) in spite of the disadvantage alluded to above. Such cars must have powerful brakes.

(*b*) *Shunt Dynamo.*—Here again it is immaterial in which direction the E.M.F. be impressed the motor will revolve in the same direction, and this will be the same direction as that in which the machine ran as a generator. This type of machine, however, cannot exceed a certain speed, as beyond this speed it becomes a generator and acts as a brake (note that in this case the magnets do not need to be reversed in polarity to produce this result). It is, however, unless supplied with absolutely constant volts, a bad starter, as at the moment of starting the armature absorbs almost all the current, the field remaining weak until the armature current falls.

A shunt wound motor, if supplied with absolutely constant volts, will, if its armature resistance be low, have a practically constant speed for all loads within its range.

(*c*) *Compound Dynamo.*—If volts be impressed at the terminals of an ordinary compound wound dynamo, it should be noted that the series winding will oppose the shunt winding. This property is made use of in some motors supplied with constant potential difference so as to get even speed at all loads. Roughly speaking, the principle is this:—Suppose the motor running at normal load, then there is a certain magnetism in the field magnets due to the effect of the shunt winding (which is, of course, quite constant with a long-shunt and nearly so with a short-shunt machine) minus the effect of the series winding, which varies with the armature current.

If now the load be from some cause suddenly removed, the armature tries to race, directly it does so its counter E.M.F. rises, and, therefore, the current through it falls, the effect of the series winding also falls and the magnets become stronger, and, therefore, the counter E.M.F. rises still further, and the machine in the act of racing acts as a brake on itself.

Motors can, for railway and other purposes, be thus "differentially compounded," as it is termed, to give constant speed at practically all loads within their range.

Commutation in Motors.

We have already seen (Chapter V) how in a generator the effect of the armature current is to rotate the neutral axis in the direction of rotation, and how, moreover, the axis of commutation is in advance of this. Now, imagine a precisely similar motor rotating in the same direction and apply the right and left hand

rules. It is evident that the current in the armature of the motor must be in the opposite direction to that in the generator.

The effect of this is to rotate the neutral axis *backwards* from the direction of rotation and a further consideration will show that the axis of commutation is still further backwards.

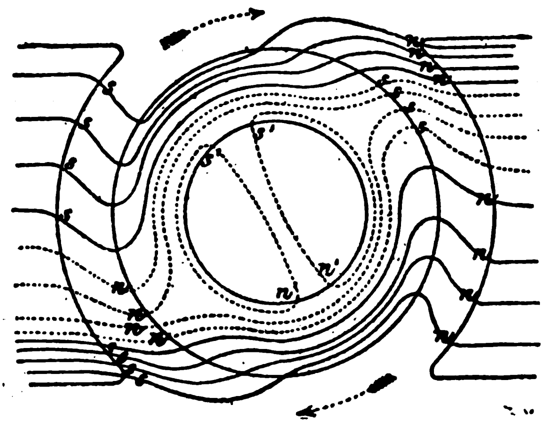

Fig. 64.

As in the case of the generator it is the coil temporarily short circuited which has to be considered. This coil must, while on short circuit, be prepared to receive the impressed current in a reverse direction to that in which it received it immediately prior to the short circuit. To effect this, the fact that the coil is the seat of an induced electromotive force due to its rotation in a magnetic field is made use of.

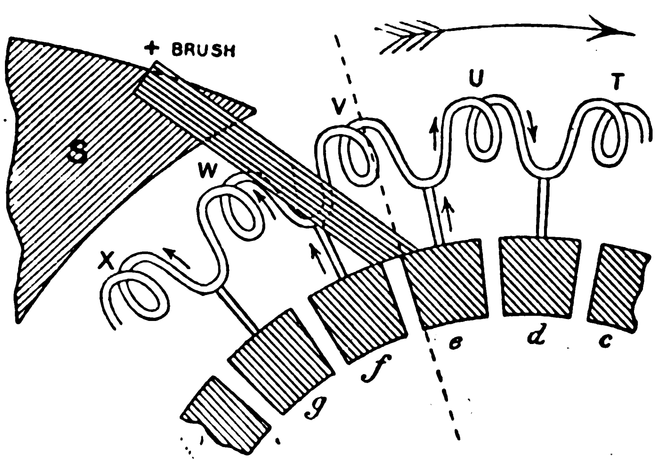

Fig. 65

An examination of the diagram on similar lines to that given for a generator (Fig. 49) will show that we must commute before arriving at the neutral axis in order that coil V may be in a fit

state to take the current as it leaves the brush, without sparking at the commutator.

From what has gone before, it should be evident that in order to reverse the direction of rotation in a motor, either the direction of the field, or the direction of the current in the armature must be reversed. It is no use to reverse both.

The most usual practice is to keep the field excited in one direction and to reverse the armature current. This is done in the elevating motor in the service Mark III projector, which is fully described in Chapter XV.

CHAPTER IX.

THE ARC, CARBONS, AND ARC LAMPS.

THE source of light used in the Service for defence electric lighting* purposes is the electric arc.

If two points of conducting material have a potential difference, whether alternating or continuous, of not more than 100 volts maintained between them, it will be found that they may be brought extremely close together before any discharge takes place between them, and the 100 volts will not produce a spark across any distance visible to the naked eye.

Should, however, the discharge once start, in consequence of their touching, then, if the P.D. be maintained, a current will still pass between them, even if they be considerably separated. This is the arc, and as stated, it is established whether the volts be alternating or continuous. In the Service, however, arc lights are invariably produced by continuous volts, and henceforth in this chapter this case only will be considered. The arc appears to be a flow of particles of which the conductors are made, taking place from the conductor attached to the positive pole of the source of power towards that attached to the negative. The heat is, however, so great that portions of the conducting particles are volatilised and pass away, and the conductors consequently waste, the positive considerably faster than the negative.

An inspection of the conductors after the arc has been burning for a short time will show that the conductor attached to the positive pole of the source of power has become hollowed at the end, whereas that attached to the negative pole will be found to be blunt-pointed. The hollow in the positive conductor is generally known as the crater.

If now a voltmeter be applied to the two electrodes while the arc exists, and an ammeter inserted in the circuit, it will be found that with large arcs, if the current remain constant, the P.D. will vary approximately with the length of the arc, and with the P.D. constant, the current will vary approximately inversely as the length, but neither quite in accordance with the laws of resistance and Ohm's law. Moreover, it is found impossible to start an arc between two points unless a certain minimum voltage be applied; for carbons this is about 35 volts for a silent arc. Why this is so it is difficult to say, but it simulates the effect of a counter E.M.F. existing in the arc.

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* The large arc lights installed in connection with the defences of a port or fortress are referred to as "Defence Lights." This term does not include the lights used for illuminating engine rooms, emplacements, or other defence buildings or posts.

In practice the electrodes are invariably formed of carbon, and consequently in future this will be assumed to be the case throughout the chapter.

The resistance of the arc would appear to consist of an approximately constant ohmic portion plus a variable dependent on the current. For large arcs, such as are used in search-lighting, the resistance of the arc may be taken as approximately

$$\left(0{\cdot}12 + \frac{5}{C(\text{amp.})}\right) \text{ ohms,}$$

and hence in order to pass a current C through it we shall require

$$C\left(0{\cdot}12 + \frac{5}{C}\right) \text{ volts}$$

to overcome the resistance, and to this we must add 35 volts to overcome the apparent counter E.M.F.

Hence, voltage required for the arc is

$$35 + C\left(\frac{5}{C} + {\cdot}12\right) = 40 + {\cdot}12\,C,$$

a formula which should be remembered and carefully worked to when dealing with inclined lamps, for whatever doubt there may be as to the exact reason, it has been well ascertained as an empirical rule that a close approximation to this formula as regards the relationship between current and volts is necessary for satisfactory working.

If with a source of constant voltage an arc is established in series with a resistance absorbing about one-fifth of the volts when the current is normal according to the above rule, then as the carbons consume away the arc increases in length and resistance, and the current will drop, and the volts at the carbons rise, and practically when working an arc the carbons should be so manipulated that the voltage between them is kept as constant as possible, and $= 40 + {\cdot}12$ C. If the voltage rise above this the arc is too long, and *vice versa*.

The material used for the electrodes, as already stated, is carbon, which is very suitable by reason of its conductivity, its infusibility, through which the rate of feed is slow, its being an inferior conductor of heat, whereby the high temperature of the arc is localised at the ends, and lastly, its cheapness.

The "carbons" are made out of gas coke, lamp-black, soot, or other material composed of almost pure carbon, ground fine and mixed with a tarry or syrupy substance rich in hydro-carbon, such as pitch or molasses. The mixture is heated, cooled, and again ground into a flour, after which the carbons are formed into the required shape either by "moulding" in steel moulds, or by being "forced" through suitable dies. After this the rods are baked at a high temperature to consolidate them and to drive off volatile impurities. The resulting product is a substance of great homogeneity, very high fusing points, and of fair electrical conductivity.

The illuminating power of the arc is approximately divided as follows:—

Positive carbon	...	...	85 per cent.
Negative "	...	...	10 "
Arc ...	...	...	5 "

For this reason the positive carbon is used as the source of light, and is presented to the reflector in various positions, as will be considered later when dealing with light distribution. In whatever manner it is presented, however, the negative will somewhat obscure the light. Taking these facts into consideration, it is evident that the *negative* should be as small as possible consistent with current-carrying capacity.

In order to reduce the diameter of the negative it is sometimes externally copper-coated, or has an extra hard core coated with copper, but in consequence of manufacturing difficulties the use of carbons of the latter nature is likely to be discontinued, their place being taken by solid carbons.

As it is important that the crater shall remain in a uniform position as regards the reflector, *i.e.* it must be practically concentric with the positive carbon, the positive has a soft core of nearly pure graphite or plumbago, in diameter about one-fourth or one-fifth the diameter of the carbon. Graphite has a better conductivity and lower fusing point than gas retort carbon, and the current is therefore tempted to remain central rather than wander to the outside of the carbon.

Sizes of Carbons.

The following table gives the sizes of carbons usually employed for arc lighting, which experience has shown to give good results:—

Current.	+ve Cored.	—ve.	Remarks.
Amperes.	mm.	mm.	
150	38	26·5	For use with horizontal lamps
120	33	23	
(Also for 120 amperes good results may be got from 38 mm. +ve and 26·5 mm. uncored —ve.)			
100-120	30	17 coppered to 19	Inclined lamps
80-100	25	16 " 17	
(These carbons may be used up to 150 and 120 amperes respectively.)			
10	13	11	Vertical lamps

All carbons before use should be thoroughly dry. They may be dried in an oven, in the smoke-box of the boiler, or any other

convenient place; spare carbons may be conveniently kept in the projector body while the arc is burning.

Lamps.

For ordinary illuminating purposes, vertical lamps, *i.e.* lamps with vertical carbons are used, sometimes illuminating directly downwards, and sometimes with a reflector below, throwing the light upwards on to the ceiling.

For defence electric lighting, for reasons which will be explained when dealing with optical appliances, carbons are frequently burned in an inclined position.

The numerous efforts to devise an automatic inclined lamp have not until recently met with any success, and now only for small lamps for optical lanterns and similar purposes. For the large currents used in defence electric lighting the hand-feed has been found the best for inclined lamps.

Inclined Lamp.

The present Service inclined lamp is known as "Lamp, Electric, Arc, Inclined. Mark III."

Mark I of this lamp is obsolete, but a large number of Mark II lamps may be found at stations. Mark III only differs from Mark II in some small points, the general principle being identically the same, but the design better in the details.

Mark III consists of a teak block $10\frac{7}{8}'' \times 4\frac{15}{16}'' \times 3\frac{1}{2}''$ wide over all, fitted with two brass blocks. The blocks and base are bored to receive a steel guide rod, 3 feet 3 inches long by $\frac{1}{2}$-inch square, and a circular steel feeding rod, fitted to an adjusting collar in the upper bearing block, to allow the lamp to be used in a 60 or 90 cm. projector.

The upper end of the feeding rod is threaded to receive the positive carbon holder, which is also fitted to the guide rod. The lower end of the feeding rod is provided with a wheel handle for manipulating the screw.

The negative carbon holder is fitted to a brass tube passing through a ball and socket joint secured to the teak base. The lower end of the tube is fitted with an insulated handle of ebonite.

Two iron bearing plates are fitted to the top of the base for supporting the lamp in the projector or adapter.

The extreme width across the plates when fixed is $5\frac{3}{16}$ inches, and the thickness of each plate $\frac{3}{16}$-inch.

A carbon screen, 4 inches in diameter, secured to a metal disc, is fitted to the guide rod and can be adjusted as required.

The object of this screen is to prevent the illumination of the ground immediately in front of the projector by direct rays from the arc.

Two brass main terminals are fitted to the base and connected by copper straps to the positive and negative side of the lamp respectively.

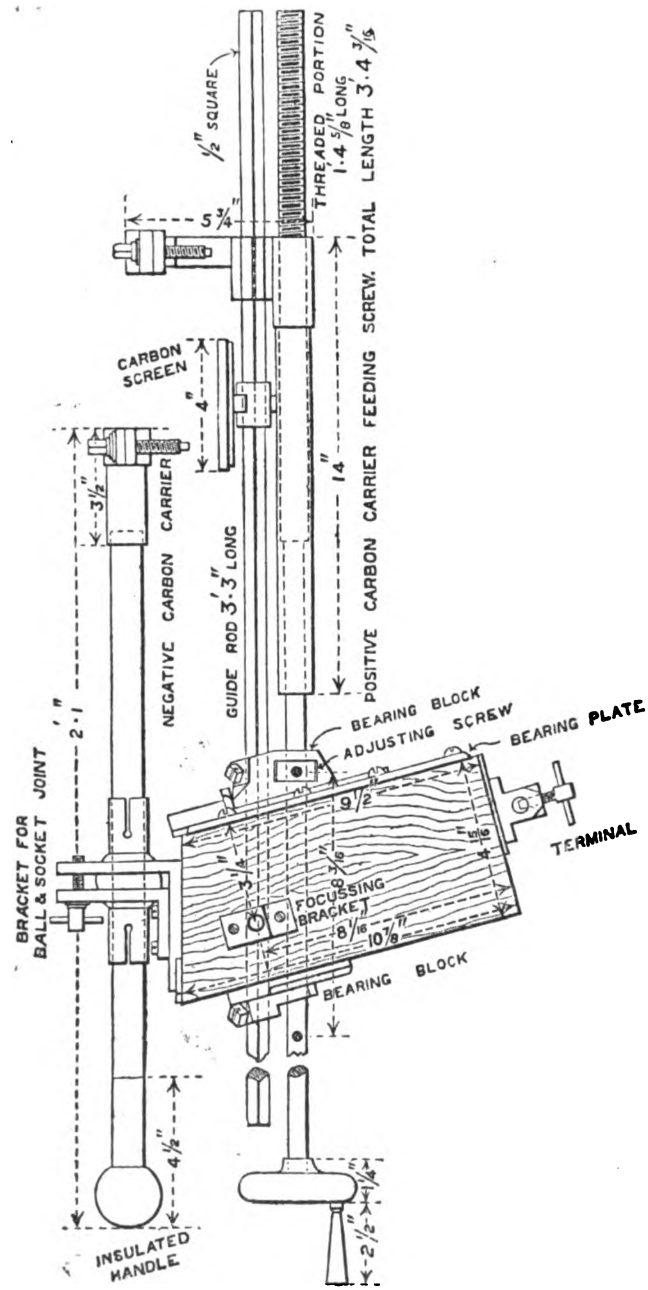


Fig. 66.

The terminals are constructed to take conductors $\frac{7}{16}$-inch in diameter.

The positive carbon holder is constructed to take carbons from

15 to 36 mm. diameter, and the negative carbon holder from 15 to 21 mm. diameter.

A brass spanner is supplied with each lamp for fixing the carbons.

The lamp is intended for use with the Mark I 90 cm. projector only, but can be used in other marks of projector in conjunction with an adapter, *vide* Chapter XI. It is suitable for currents up to 150 amperes.

The lamp weighs about 30 lbs., and fits into a packing case of the following external dimensions:—

	Excluding Ledges and Cleats for Handles.	Over all.
	Ft. in.	Ft. in.
Length	3 10	4 2
Width	1 6	1 6
Depth	0 8½	0 10

Instructions for Managing the Arc when Using the Inclined Lamp.

1. The end of the positive carbon should be filed away at an angle of 45°. The negative should be roughly pointed (see Fig. 67).

2. The carbons should be firmly clamped in the holders, the centre of the positive being as nearly as possible at the focus of the mirror, and the inclined face towards the mirror.

The carbons should be adjusted so that when they are brought together by working the lamp, the negative touches a point about 4 mm. in front of the centre of the positive crater (see Fig. 67).

3. Having seen that the carbons are not touching one another, and then the engine having been started, the switch should be closed, a short contact (make and break) being first tried to see that there is no short circuit; if there be one, a flame (arc) will be seen at the switch, when the circuit is broken; if there be no short circuit the switch may be firmly closed.

4. Close the carbons by means of the distancing screw and immediately separate a short distance; not too far, or the arc which is immediately established will go out.

5. Time having been given for the carbons to get thoroughly heated, they may now be gradually separated till a steady silent arc is obtained.

6. From time to time the carbons should be fed together, the positive being lowered by means of the hand-wheel, while the negative must be occasionally pushed up so as to keep the arc in the focus of the reflector.

7. The proper relative position of the carbons is maintained by means of the ball and socket joint. The crater must be kept facing the mirror as much as possible.

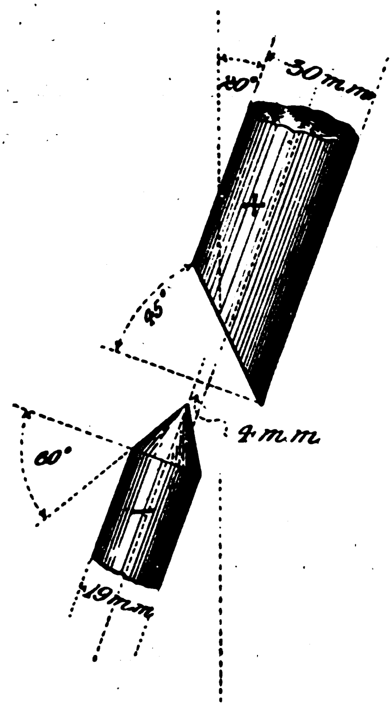


Fig. 67.

8. With inclined lamps the arc will inevitably burn unsteadily from time to time, owing to the carbons losing their shape.

If the crater becomes unduly elongated the tail must be burnt off by approaching the negative to that part. If, on the other hand, the crater be found to be facing too much downwards, the negative carbon must be brought towards the front of the crater, so as to consume it away until its proper aspect is restored.

If the negative carbon has become blunt the arc will sometimes wander from one spot to another, and flare up the sides of the positive. This is due to there being no definite point on the negative which is nearer than any other to the positive.

When this happens the hissing arc will have to be employed for a short time, the carbons being brought close together. Carbon will be found to be deposited on the negative, which will grow into a head like a mushroom. When the mushroom head has formed, the carbons should be slightly separated so as to stop the hissing. The edges of the mushroom head will then drop off, and eventually a good point will be formed.

9. The points must never be kept in contact, or the insulation of the dynamo will be liable to damage from overheating.

10. If the light goes out, the points should be brought together, and the arc established as quickly as possible.

11. When the light is no longer required the engine should be slowed down, or the carbons gradually separated, till the light

goes out. The switch must not be broken with the full current on except in cases of emergency.

General Remarks.

Steady hissing is generally due to too short an arc; unsteady hissing generally points to impurities in the carbons.

Excessive flaming may be the result of too long an arc, but can hardly be considered a defect if the arc is otherwise going well.

Horizontal Arc Lamp.

LIST OF PLATES.

I.—Description of the Lamp.

Nomenclature.

1. The *vocabulary* nomenclature for the lamp is as follows :—

Designation.	Detail.
LAMPS, ELECTRIC, Arc, Horizontal,	Automatic and hand. For use in projectors, as under, with short focus reflectors
90 cm. projector ...	For Mark II and III projectors 120 to 150 ampères, Schuckert model Without accessories

The accessories are described in Section VIII of this description.

The lamp referred to is constructed for either hand-working for currents not exceeding 150 amperes, or automatic working for currents of 120 to 150 amperes, with a potential difference at its terminals of 60 volts.

Lamps designed for currents of from 90 to 120 and for from 60 to 90 amperes have been supplied for service requirements. These lamps are similar generally to that described here.

Body of Lamp.

2. The lamp has a brass body 19¾ inches long, 10¼ inches wide, and 7¾ inches deep, and weighs about 104 lbs.

The body is provided with projecting guides, G G (*Plate* III), along the upper edges for about half its length. These guides fit into corresponding grooves in the projector body, the lengths of the guides and grooves being so arranged that it is not necessary to remove the "front door" to insert the lamp in the projector.

Lifting Tray.

3. For convenience in carrying the lamp about, a "lifting tray" is provided, consisting of a shallow rectangular tray made out of sheet iron, fitted with four stout iron handles.

This lifting tray is provided with, and forms part of, the projector.

Carbon-holders and Carbon-carriers.

4. The carbons are supported in a horizontal position by the carbon-holders, secured to the tops of the carbon-carriers (*Plate* III). Each carbon-carrier is supported upon wheels, so that it can move easily in a horizontal direction. Electrical connection is maintained between the carbon-carriers and the fixed conductors in the lamp by means of flexible leads. In the case of the positive carbon-carrier these leads are three in number, contained inside the body of the lamp. In the case of the negative carbon-carrier the connection is external, and consists of an insulated pillar on the top of the lamp box and a number of strips* of copper foil between it and the carbon-carrier.

Arc-striking Magnets.

5. The lamp is provided with a pair of horseshoe magnets M (*Plate* IV), wound in the usual way, one with shunt, and the other with series coils. These magnets act on a rocking shaft N (*Plate* III), by means of an armature O, rigidly attached thereto; the shunt-wound horseshoe magnet acting in opposition to the series-wound horseshoe magnet. They serve the purpose of striking the arc, and of *quickly* altering the length of the arc to suit any *sudden* variations of current due to bad or irregular

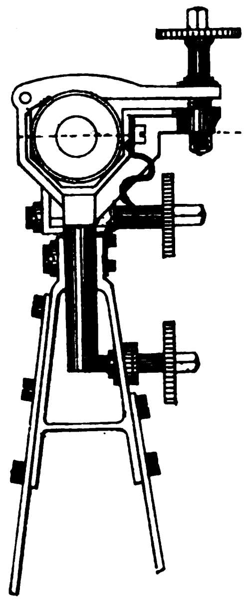
* These strips should be bound over with "primed tape" or other suitable insulating material, in order to prevent electrical contact between them and the positive carbon-carrier when the carbons are nearly burnt out.

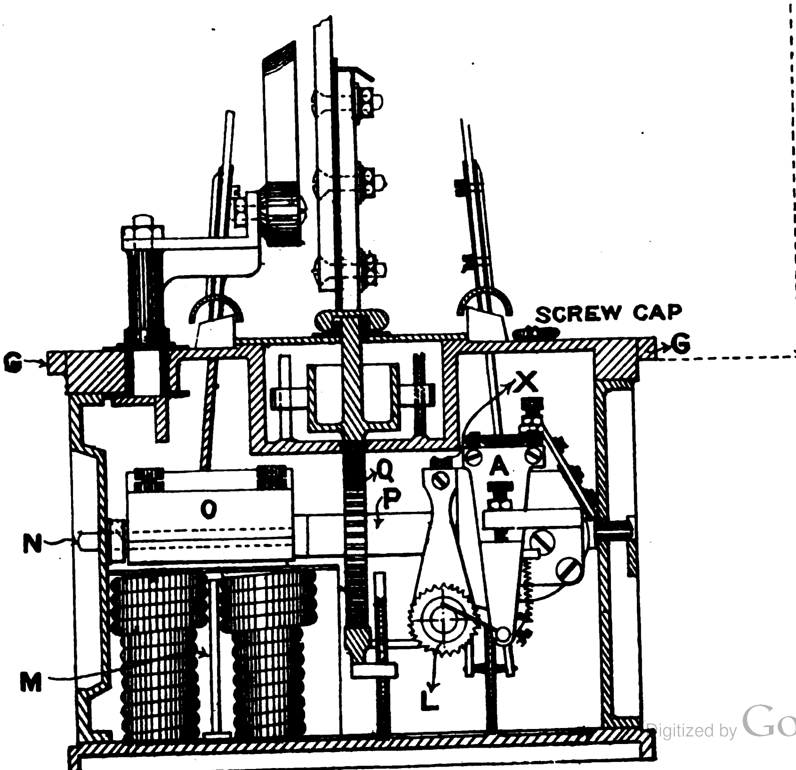
VIEWS.

TAL ARC LAMP.

HAND.

amp with the side and
np body removed.





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carbons, &c. This they effect through the following means (see *Plate* IV):—

The rocking armature O is keyed to the shaft N, and can cause it to rock; the feeding rod K is carried on a framework attached to the automatic feeding magnet F, which is also keyed to the shaft N, and consequently rocks with the armature of the arc-striking magnets; the feeding rod has a worm thread cut on it at W, which engages with the wheel X, which is keyed on the same sleeve P as the wheel Q, which sleeve P rides loose on the rocking shaft N. Consequently when O rocks, Q partially revolves, and moves the carbon-holders in doing so.

A "damping" arrangement is fitted to the rocking armature to prevent these alterations being too suddenly effected, and to check the effect of the inertia of the moving parts. To the rocking armature are rigidly fixed two short arms. To the end of one of these is jointed the cylinder of an air "dash-pot," the piston rod of which is fixed to the bottom of the lamp box. To the end of the other arm two opposing helical springs are secured, the other extremities of the springs being attached to the top and bottom of the lamp box respectively. The springs are so arranged that neither exerts any pull on the arm when the ends of the rocking armature are equidistant from the poles of the arc-striking magnets. In the lamps of earlier manufacture the dash-pot was not fitted, and its functions were indifferently performed by means of a friction brake acting on the opposite end of the rocking shaft.

Feeding Magnet.

6. To feed the carbons together as they burn away, a second electro magnet F (*Plates* III and IV) is employed. The body of this magnet is keyed to the rocking shaft, and carries with it its own armature and a steel spindle K, to which is attached a ratchet wheel L, and a hand feeding wheel H (for hand working) The feeding magnet is shunt-wound, and its armature J (*Plate* IV) is provided with a make and break device regulated by an adjustable tension spring, as in a "trembling" bell, by means of which it is caused to vibrate as soon as the "voltage" on the terminals of the coil reaches a definite value, depending on the adjustment of the lamp. The armature carries a pawl, the reciprocating movement of which causes the ratchet wheel and rod K to revolve. A sleeve P (*Plate* IV) rides loosely on the rocking shaft and carries a spur wheel Q, and worm wheel X, both rigidly attached to the loose sleeve. The spur wheel engages in two racks R R, the upper rack being attached to the negative carbon-carrier, and the lower rack to the positive carbon-carrier. The worm wheel engages in a worm W, cut upon the feeding rod K, so that any rotation of the feeding rod is thereby communicated to the carbon-carriers independently of the motions of the rocking armature, while at the same time, as was shown when speaking of the arc-striking magnets, any rocking of the armature of the arc-striking magnets

about its own axis, moves the carbon-carriers independently of rotation of the feeding rod.

Switches and Adjustable Resistances.

7. The shunt wound coils of the arc-striking magnets and the coil of the feeding magnet can be disconnected by a switch when the lamp is to be worked by hand. This switch D (*Plate* IV) is controlled by a metal arm or switch lever E, on the back of the lamp, which in addition to manipulating the switch, secures the feeding rod when the lever is down and the lamp arranged for hand working.

To assist in the regulation of the lamp, adjustable resistances are also provided in circuit with the above coils. These resistances are contained in the base of the lamp box, and are controlled by two finger switches (*vide. Plates* IV and V) on the end of the lamp close to the hand feeding wheel H.

The leads and connections are all entirely insulated from the body of the lamp.

II.—Details of Circuits through the Lamp.

A. When the switch lever is placed "up," *i.e.* in its vertical position, the circuits through the lamp are three in number, arranged as follows (see *Plate* V) :—

1.—*Main Circuit.*

(*a*) From positive terminal by a copper strap and flexible connections to the positive carbon-carrier.

(*b*) Thence by positive carbon across the arc to negative carbon and negative carbon-carrier.

(*c*) Thence by a flexible connection and an insulated pillar on the top of the lamp body to the series coils of the arc-striking magnet. These coils are two in number, wound in parallel.

(*d*) Through these coils to the negative terminal.

2.—*Circuit of Shunt Coils of Arc-striking Magnets.*

(*a*) From the positive terminal to the disc switch (the switch lever being up).

(*b*) Disc switch to one end of the shunt coils of the arc-striking magnets. These coils are two in number, wound in parallel.

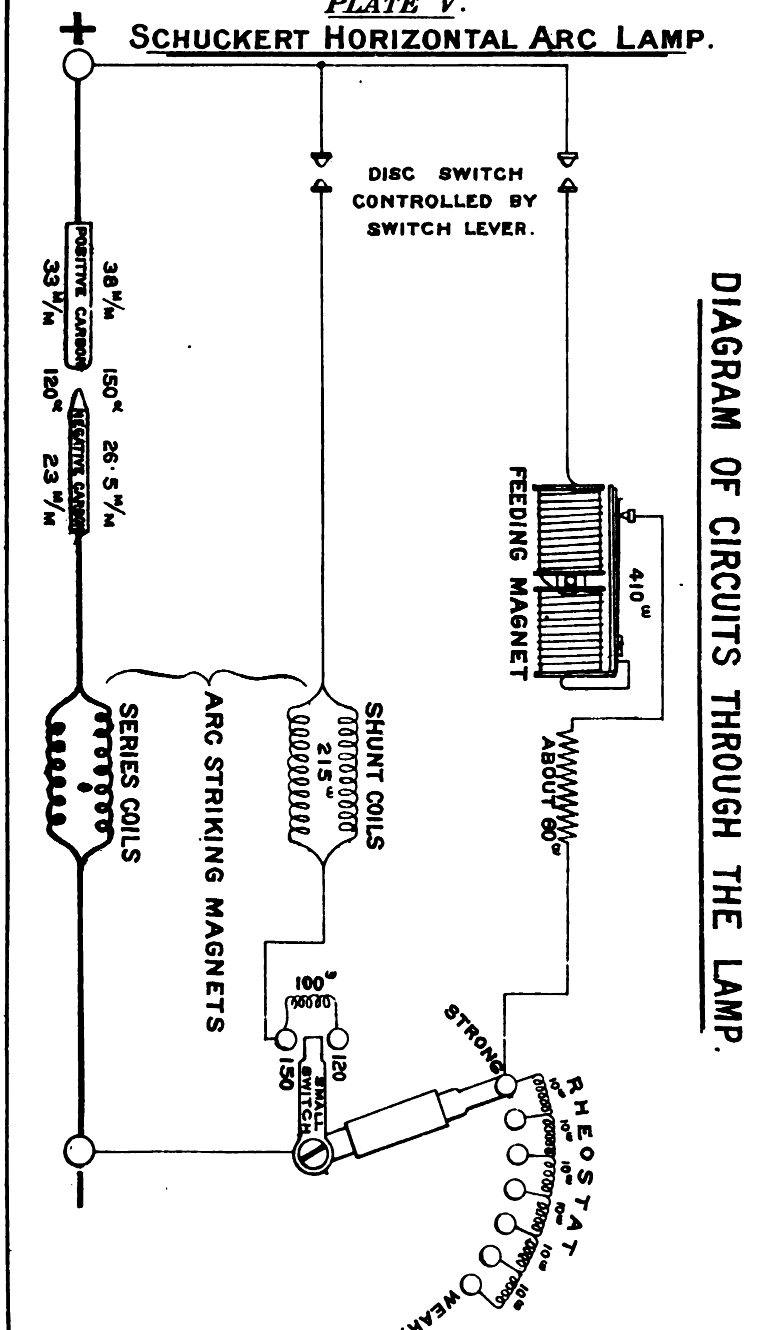
(*c*) Through these coils to stud on back of lamp marked 150.

(*d*) Thence through a resistance of about 100 ohms to stud marked 120; thence along finger of small switch to negative terminal.

To face page 94.

PLATE V.

SCHUCKERT HORIZONTAL ARC LAMP.



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3.—*Circuit of Coil of Feeding Magnet.*

(*a*) From the positive terminal to the disc switch (the switch lever being up).

(*b*) Disc switch by flexible connection to one end of feeding coil.

(*c*) Through coil of feeding magnet to contact spring on armature.

(*d*) Thence to contact stud; thence by a flexible connection to a resistance of about 60 ohms in base of lamp body.

(*e*) Through resistance of 60 ohms to left-hand stud of seven-point rheostat. Six coils, each of 10 ohms resistance, are connected in series with the resistance of 60 ohms above referred to, and one or more of these can be placed in circuit by means of the rheostat switch.

(*f*) Through finger of this switch to negative terminal.

B. When the switch lever is placed "down," *i.e.* in its horizontal position, all the coils and resistances with the exception of the "series coils" of the arc-striking magnets are cut out.

III.—Resistances of Coils, etc.

The resistances of the various coils are approximately as follows:—

Arc-striking magnets	Series coils, two in parallel, very low, practically negligible. Shunt coils, about 215 ohms; *i.e.* two coils in parallel about 430 ohms each.

Feeding magnet coil, about 410 ohms.

Resistances in base of lamp:—

Between feeding magnet coil and left hand, stud of rheostat	60 ohms.
Between each pair of studs of rheostat, 10 ohms, making a total of	60 ohms.
Between studs marked 150 and 120	100 ohms.

IV.—Adjustments.

Caution.—Before turning the hand feeding wheel by hand, always press it in, in order to throw the pawl and ratchet out of gear and prevent injury to them.

To Adjust the Lamp.

1.—*For Hand Working:*—

(*a*) Press in the feeding wheel. This should throw pawl and ratchet out of gear.

(*b*) Clamp down the feeding rod with the switch lever. This should disconnect the shunt coils of the arc-striking magnets and the feeding magnet coil from the positive terminal. In the most recent pattern lamps, a collar is fixed on the feeding rod close to

the hand feeding wheel, to prevent the withdrawal of that wheel after the switch lever has been clamped down, and it should be noted that this collar is between the switch lever and lamp body before the hand feeding wheel is turned by hand.

2.—*For Automatic Working*:—

(*a*) Release the feeding rod by raising the switch lever. This should connect the shunt coils of the arc-striking magnets and the feeding magnet coil to the positive terminal.

(*b*) Pull out the hand feeding wheel. This should throw the pawl and ratchet into gear.

(*c*) See that the hand feeding wheel turns when the armature of the feeding magnet is worked by hand.

If it does not turn either—

(i.) The clamping collars S S, shown in *Plate* III., are loose, and the pawl has in consequence fallen on one side or other of the ratchet wheel; or

(ii.) The pawl is damaged or out of adjustment; or

(iii.) The teeth on the ratchet wheel are damaged.

(*d*) Adjust the distancing screw A, *Plate* III., so as to allow the armature a play of about $\frac{3}{16}$ths of an inch.

(*e*) Adjust the contact point by the screw B, so to have a clearance of about $\frac{1}{4}$th of an inch when the armature and contact spring are pressed hard down.

(*f*) Adjust contact spring so that the circuit through the feeding magnet coil is *just* broken when armature is pressed right down. This adjustment is made by means of the screw C, which is got at through a hole, covered with a screw cap, in the top plate of the lamp box. To make it, place a cell and "detector" in simple circuit with the lamp terminals. Temporarily break the circuit through the shunt coils of the arc-striking magnets. (This can usually be done by setting the switch of this coil's circuit at an intermediate position between the studs marked 150 and 120. If it cannot be so done, place a piece of paper between the arm of the switch and the studs). No carbons should be in the lamp, or if there are they must be separated. Press armature down, and screw down C until deflection just goes off.

Clamp the screw C, and replace the screw cap after making the adjustment. Restore the circuit of the shunt coil of the arc-striking magnet.

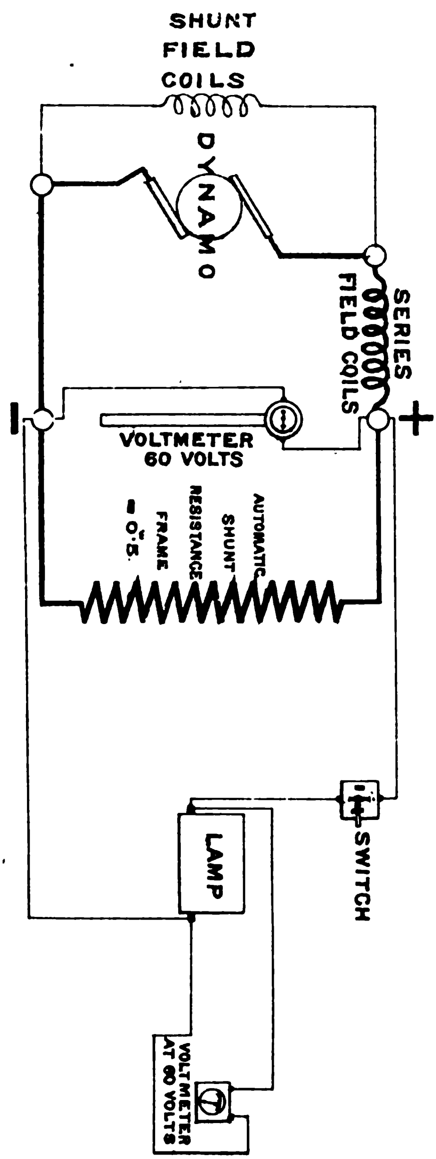
(*g*) By means of the capstan-headed screw D, which regulates the tension of the spring, adjust the armature to work when the volts at the terminals of lamp are 60, and the switch of the rheostat is on the central stud. This adjustment may very well be made while the lamp is burning.

If it be desired to make the adjustment when the lamp is not burning, the volts may be obtained from a dynamo by connecting up as shown in *Plate* VI., and take the following steps:—

A resistance of 0·5 ohms, capable of carrying 120 amperes, should be connected to the terminals of the dynamo so as to put a fair load on the engine, and the dynamo should be run to give 60 volts at its terminals. The shunt resistance (*vide* p. 163) which is used in conjunction with the automatic switch is suitable for this purpose.

PLATE VI.

SCHUCKERT HORIZONTAL ARC LAMP.



CIRCUIT FOR ADJUSTING LAMP WHEN NOT WORKING.

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Press in the hand feeding wheel in order to throw the pawl and ratchet wheel out of gear.

Separate the carbon-holders.

Raise the switch lever, to bring the coil of the feeding magnet into circuit.

Connect the terminals of the lamp to the terminals of the dynamo by two small leads and a switch.

Adjust the armature as above.*

There will be practically no loss of volts in the leads, because the current will be so small.

(*h*) See that the brake or dash pot is in working order.

V.—To Commence Working.

A. For Hand Working:—

1. Place the lamp, adjusted for hand working in the manner described in Section IV., in the projector and fix the carbons in their holders, leaving the points separated about half an inch.

2. Switch on the current and bring the carbon points together by hand, immediately separating them by hand until a proper length of arc is arrived at. The volts at the lamp terminals should be just under 60: the current should be 120 or 150 amperes, according to the size of the carbons in use.

B. For Automatic Working:—

1. Place the lamp adjusted for automatic working in the manner described in Section IV., in the projector and fix the carbons in their holders, leaving the points separated about half an inch.

2. If the lamp is fitted with a brake see that it is applied firmly.

3. Place the small switch on the stop marked 120. This is always done at starting, no matter what current it is proposed to work at, as the power of the shunt coil of the arc-striking magnets is thereby reduced, and the oscillations which sometimes occur when the current is first switched on are somewhat checked. This precaution, though it should be taken, ought not to be (and generally is not) absolutely necessary in the case of lamps fitted with a dash pot.

4. Switch on the current. It is well immediately to separate the carbon points by hand (bearing in mind the caution given above in Section IV.) to reduce the excessive current, which in consequence of the large soft core to the positive carbon, almost invariably exists for a few minutes if the lamp is allowed to start entirely automatically.

5. When the arc has settled down, move the small switch to the stop marked 150, if the current to be used exceeds 135 amperes.

6. Adjust the rheostat switch so that the feeding magnet coil causes its armature to vibrate when the volts on lamp terminals

* All adjusting screws of the feeding magnet coil are provided with lock nuts. These should invariably be tightly screwed up as soon as the adjustments have been made.

reach 60. Should the armature vibrate when the P.D. at terminals of lamp is less than 60 volts, the switch must be moved towards the right hand side, and conversely. Each step will make a difference of about one volt in the P.D. required at lamp terminals to cause "feeding."

VI.—While the Lamp is Burning.

1.—*To Change from Hand to Automatic Working.*

(*a*) Gradually raise the switch lever and at the same time turn the hand feeding wheel (without pulling it out) so as to open the carbon points sufficiently to compensate for the distance they would be closed by the release of the feeding rod.

(*b*) Pull out the hand feeding wheel to throw the pawl and ratchet into gear.

(*c*) Adjust the rheostat switch.

2.—*To Change from Automatic to Hand Working.*

(*a*) Move the switch of rheostat on to the left hand stud and wait if necessary until the armature of the feeding magnet ceases to vibrate, then move the switch hard over to the right. The object of this is to prevent the armature of the feeding magnet from working, and thereby giving slight shocks to the operator, while the following adjustments are being made.

(*b*) Press in the hand feeding wheel to throw pawl and ratchet out of gear.

(*c*) By means of the switch lever gradually clamp down the feeding rod, and at the same time turn the hand feeding wheel so as to close the carbon points sufficiently to compensate for the distance they would have been opened by the movement conveyed to the rocking shaft.

It may be useful to remember that when clamping down or releasing the feeding rod, the feeding wheel should be turned in the direction that the switch lever is moved.

VII.—Action of the Lamp.

The action of the lamp when set for hand working requires no further explanation.

The action of the lamp when set for automatic working is briefly as follows:—

When the main switch is closed, a difference of potential is established at the lamp terminals, a current therefore flows through the shunt coils of the arc-striking magnets and one end of the rocking armature is pulled down. This armature being geared through the feeding rod to the spur wheel which gears into the racks fixed to the carbon-carriers, the above movement of the armature causes the carbons to move towards each other, and possibly to touch, so completing the main circuit. Should, however, the movement of the rocking armature be insufficient to cause contact between the carbons, the feeding

magnet will operate its armature and gradually close the carbons, through the agency of the pawl and ratchet wheel, until they touch and complete the main circuit.

As soon as the main circuit is completed, a large current flows through the series coils of the arc-striking magnets, and that end of the rocking armature is then pulled down, the carbon points separated, and the arc struck.

The construction of the lamp is such that when the arc has reached its proper length, the pulls of the shunt and series coils of the arc-striking magnets are equal.

As the carbons burn away the volts gradually rise; and as soon as they reach 60 the current through the coil of the feeding magnet is sufficiently strong to attract its armature, causing it to vibrate and so feed the carbons gradually together until the volts fall below 60.

When the carbons have been so fed together that the distance between the carbon-holders is reduced to about 6 inches, an insulated stop Z (*Plate* IV) on the inner end of the lower rack comes in contact with one of the springs of the disc switch and breaks the circuit through the coil of the feeding magnet. Further effort to close the carbons by means of the hand wheel presses the spring against the back of the lamp body and the travel of the rack is prevented.

Caution.—When the total length of a carbon is reduced to 4 inches a fresh carbon should be fitted to the lamp.

The resistance between the studs marked 120 and 150 is inserted in the circuit of the shunt coils of the arc-striking magnets when the main current it is intended to use is about 135 amperes or less, so as to diminish the pull of those coils in the same proportion as the pull of the series coils. The number of volts used at the lamp is the same for all currents between 120 amperes and 150 amperes. Therefore, as in the arc-striking magnets the shunt coils (the current through which depends on the volts at lamp terminals) are constructed to be equal in pull to the series coils when the main current is 150 amperes, it is obvious that when the main current is reduced to 120 amperes, the shunt coils would be the stronger, and too short an arc would be burned for a time, unless provision had thus been made for inserting extra resistance in the circuit of the shunt coils of the arc-striking magnets when using only 120 amperes.

VIII.—Arc Deflector.

With horizontal arc lamps an "arc deflector" is used to counteract the tendency of the electric arc between the carbons to burn principally at the upper edges of the carbons.

The arc deflector consists of a piece of soft iron, $\frac{9}{32}'' \times \frac{31}{32}''$ in section, bent into the arc of a circle such that the partial ring so formed has an inside diameter of $4\frac{13}{16}$ inch. It is fixed to the projector body by means of two corrugated brass supports as shown in Fig. 94, p. 141.

Although arranged to be concentric with the positive carbon,

the arc deflector is not placed directly below the electric arc, but is fixed so that when the lamp is correctly focussed the edge of the arc deflector nearest to the electric arc is 30 mm. (= $1\frac{3}{16}$ inch about), further from the reflector than the tapered end of the positive carbon.

The object of this is to keep the arc deflector from being damaged by the heat given out by the electric arc.

IX.—ACCESSORIES.

The following accessories are required for use with the lamp. They are described below in accordance with their *Vocabulary* nomenclature:—

Designation.	Detail.
LAMPS, ELECTRIC, Arc, Horizontal, 90 cm. projector, Accessories	In wood case

PARTS comprising One Set of Accessories.

Designation.	Detail.	No.	Remarks.
Bits, rose	For positive carbons ...	1	
Bottles—			
Glass	Oil, in tin case	1	
Tin	For instrument oil, ¼ pint	1	
Box, wood	To contain accessories ...	1	
Brushes—			
Camel-hair, 1¼″ ...	Flat	1	
Paint, sash tool, No. 2	... ...	1	
Watchmakers' ...	Telegraph equipment ...	1	
Cleaners, contact ...	... ...	2	
Conductors, flexible—			
Positive	Silk covered	3	
Negative	Copper strip	1	
Drivers, screw—			
13 mm.	Steel, handled	1	
9 mm.	... ...	1	
7 mm.	... ...	1	
4 mm.	... ...	1	
3 mm.	... ...	1	
Ferrules—			
Brass—			
38 mm.	For positive carbon ...	2	
26·5 mm.	For negative carbon ...	2	
Gunmetal—			
33 mm.	For positive carbon ...	2	
23 mm.	For negative carbon ...	2	
Files, bastard, safe edge, 10″	Handled	1	
Leather, chamois ...	... ...	1	
Lugs, gunmetal... ...	Tinned, for lamp terminal	2	
Nuts	Of sorts, for repair of lamp	9	

PARTS comprising One Set of Accessories—continued.

Designation.	Detail.	No.	Remarks.
Pin, adjusting	Steel	1	
Pins, securing	For repair of lamp ...	4	
Rags, cotton	Fine, white ... ozs.	1	
Screws	Of sorts, for repair of lamp	49	
Springs, pawl	For ratchet wheel ...	2	
Spanners—			
Box, hexagonal ...	Gunmetal, 18 mm., for main terminals	1	
Box, square, 8 mm. ...	Wood handle, for carbon holder	2	
Double ended, 12 and 14 mm.	Steel, for nuts	1	
Double ended, 10 mm.	Steel for nuts	1	
Forked, small ...	Gunmetal, for nuts of switch	1	
Forked, large... ...	Gunmetal, for screw collars of main terminals	1	
Tips, oil	Brass, with screw cap ...	1	
Tongs	For carbons ... pairs	2	
Washers, insulating ...	Various, for repair of lamp	42	
Wheels, ratchet... ...	For repair of lamp ...	1	

X.—CARBONS.

The following are the carbons for use with this lamp. They are described below in accordance with their *Vocabulary* nomenclature:—

Designation.	Detail.
CARBONS	For electric arc lamps
Horizontal lamps	10 inches long
Negative—	
26·5 mm.	For 150 amperes
23 mm.	For 120 amperes
Positive—	
38 mm.	For 150 amperes
33 mm.	For 120 amperes

Partly in consequence of the difficulty of making satisfactory negative carbons with hard cores as previously mentioned, and partly for other reasons which need not be discussed here, the most recent trials indicate that it is expedient to use rather smaller currents with the carbons specified in the above table.

In conjunction with glass reflectors of short focal length, a normal full working current of 120 amperes must not be exceeded, and for this current the 38 mm. cored positive and a 26·5 mm.

solid negative should be used. Further supplies of the following carbons are, therefore, not likely to be made, viz. :—

Carbons positive ...	...	33 mm.
„ negative ...	...	26·5 mm. (with hard core).
„ „ ...	...	23 mm.

Vertical Arc Lamps.

The arc lamp in use in the Service for general illuminating purposes is known as "Lamp, vertical, 10 amperes." The majority of those hitherto purchased have been of the type known commercially as the Brockie Pell arc lamp.

This lamp depends for its action on the differential working of two coils, one in series with the arc and one in shunt across the arc, in the same manner as already described in the horizontal arc lamp.

The feeding is done by gravity, and the action is as follows; *vide* Plate VII :—

The carbons of the lamp are normally touching each other, by reason of the greater weight of the upper or positive carbon-holder. On the switch being closed, there is a rush of current through the series coil, which accordingly raises the core into the coil. In so doing the rod marked "*a*" is also raised and tightens a chain round the wheel "*c*," rotating this wheel slightly in a clockwise direction (*vide* Fig. 2), thereby opening the carbons and striking the arc.

The arc being struck continues to burn and the volts across it gradually rise; as the volts rise so the shunt coil gains power and draws its core up thereby bringing the carbons closer together, the wheel being still locked by the chain. When, however, the carbons are brought close enough for the movable arm "*d*" to come against the fixed pin "*b*" the tension is taken off the chain and the carbons feed together by gravity.

These lamps are constructed to burn across a 50-volt circuit, with 42 volts at the terminals of the lamp, the current being 10 amperes, *i.e.* when burning on a 50-volt circuit, 8 volts should be lost in leads or resistance.

The carbons used are 13 mm. positive and 11 mm. negative, Should a diffused light be desired, rather than brilliant illumination, a reflector should be placed *under* the lamp, so as to throw the light from the crater on to the ceiling, which should be whitewashed. This will give a pleasant light, though somewhat weak, almost without shadows, and far less trying to the eyes than the direct light from the arc.

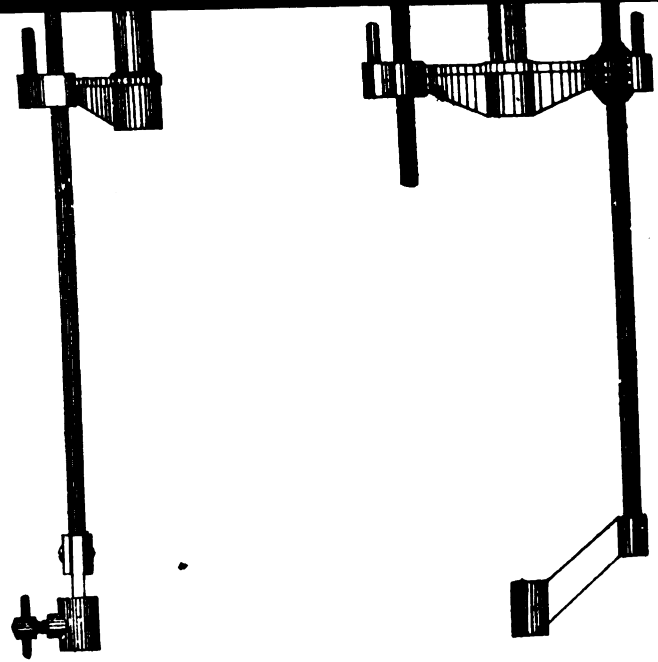
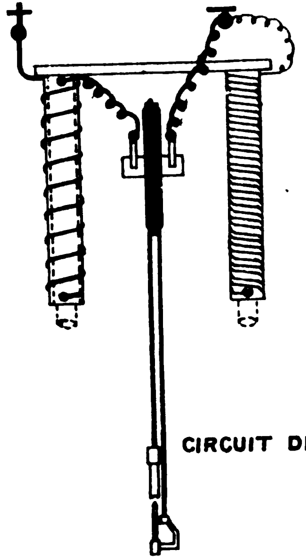


FIG 4.



CIRCUIT DIAGRAM

733.6 1900

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CHAPTER X.

OPTICS OF ELECTRIC LIGHT PROJECTION.

LIGHT–PROJECTION BY THE HELIOGRAPH.

As an introduction to the subject of the optics of Electric Light Projectors, it will be convenient to consider a rather simple case of light-projection, namely one which occurs with the heliograph. **Introductory remarks.**

The Service heliograph consists of a plane circular silvered glass mirror, 5 inches in diameter.

It is now proposed to consider the simplest case of the use of the heliograph, not that of duplex working.

In order further to simplify the problem the mirror will be considered as a plain metallic reflector without any glass; this assumption will not materially affect the accuracy of the conclusions arrived at.

The sun may be considered as a spherical source of light sending out light in a precisely similar manner from every part of its surface.

It is clear that every part of the sun's surface facing the heliograph mirror, however obliquely, sends rays of light to every part of that mirror. This may be otherwise stated by saying that every part of the heliograph mirror receives rays from every part of the sun's surface that faces that mirror, however obliquely. It will sometimes be more convenient to consider this statement of fact in the former and sometimes in the latter aspect.

By far the larger number of the rays emitted from the sun's surface, of course, do not fall on the heliograph mirror; all such rays are lost as far as heliographing is concerned. We are only concerned with those falling on the mirror.

Inasmuch as we know from actual observation that all parts of the sun's visible surface as seen from any point on the heliograph mirror appear equally brilliant, it is clear that for any given relative positions of the sun and that mirror the effect produced is just the same as if the spherical sun were replaced by a plane disc at right angles to the straight line joining the centre of the sun and the centre of the heliograph mirror, the brilliancy of which disc was everywhere the same as that at the part of the sun's surface cut by the line joining the sun's centre to the centre of the heliograph mirror.

Consider the central part of the heliograph mirror. A cone of rays of light falls on it as shown in the diagram below, and will be reflected as there shown; for it is well known that the diameter of the sun and its distance from the earth are relatively such that its diameter subtends an angle of 32 minutes at the earth's surface. **Influence of shape of heliograph mirror.**

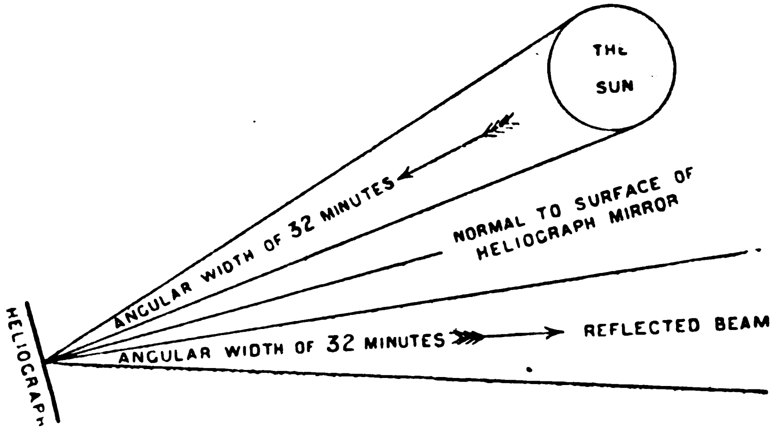

Fig. 68.

It is, of course, evident from what has been said above regarding the sun's disc, that all parts of the base of this cone of reflected rays will be equally illuminated.

Now, since the dimensions of the heliograph mirror are very small—infinitesimal, in fact—as compared with the sun's diameter and distance from the earth, every part of the surface of the mirror may be regarded as in exactly the same case as the central part of the mirror. Each part of the mirror receives and reflects, then, such a cone of rays of light.

At a considerable distance from the mirror, such as 1,000 yards for instance, all these cones of light will be practically exactly superposed; for the greatest dimension of the mirror (2½ inches for the distance of a point on the circumference from the centre of the mirror) disappears entirely in comparison with the radius of the base of each of these cones of reflected rays (roughly 160 inches at 1,000 yards), being only about 1/64th part, or about 1½ per cent., of it.

It is this fact that brings it about that at any working distance (for signalling purposes) the beam thrown from the heliograph mirror may be regarded as a right cone with its apex at the centre of that mirror and its base a circle *whatever the shape of the heliograph mirror*, whether circular, elliptical, square, or triangular, &c., &c., provided, of course, that it is a *plane* mirror.

It is very important to grasp this fact.

It is not always as clearly recognised as it ought to be; because at short distances from the heliograph mirror the cross section of the reflected beam resembles the shape of the projection, on a plane at right angles to the direction of the reflected rays, of the outline of the heliograph mirror; and consequently would not generally be circular, but (Service heliograph mirrors being invariably themselves circular) would be elliptical. And it so happens that it is at short distances from the heliograph mirror that the shape of the reflected beam is most often observed.

Of course the smaller the heliograph mirror, or the larger the

angle subtended at its centre by the distant source of light, the less the distance from the mirror at which the reflected beam assumes this simple conical form. This suggests a simple method of verifying the statement, namely in the following way. Cover the heliograph mirror with a sheet of paper with a square of ½ inch side, an equilateral triangle of ½ inch side, and a circle of the same diameter, cut in different parts of it: thus in effect making from the one mirror three heliograph mirrors each very small indeed, in the same plane and pretty close together. Take the reflected beams from the parts of the mirror left exposed, where these holes are cut, on a surface normal to the reflected rays and about 12 feet distant from the mirror: all the luminous areas on that surface will appear as circles. Now move the surface up towards the mirror till it is only about 12 inches from it: the luminous areas on it will now be oblong, triangular, and elliptical respectively. At a distance of about 12 yards from the mirror these three beams will be all merged in one cone with a circular base.

Influence of size of heliograph mirror.

Moreover, we note that since at working distances each part of the mirror contributes its cone of rays, and all these cones are alike and are superposed, the intensity of the illumination produced at the far station (*i.e.* the amount of light thrown on each element of area on which it falls) is proportional to the size, irrespective of the shape, of the mirror. Hence a 5-inch diameter heliograph mirror at any given considerable distance produces 25/9, or nearly three times as great an intensity of illumination as a 3-inch diameter reflector.

The area illuminated at any distance, commonly called the width of the beam, is, however, the same for all diameters and shapes of heliograph mirror, being of course that due to the angular width of the sun as seen from the earth.

Influence of obliquity of plane of heliograph mirror to line joining its centre to centre of sun.

Consider next how the reflected beam from a given heliograph mirror is affected by variations in the angle between the straight line joining the centres of the sun and the heliograph mirror, and the straight line joining the centre of the heliograph mirror and the point on which the heliograph is laid.

Fig. 69 shows two cases where the same sized and same shaped heliograph is set up to reflect the sun's rays in two different directions.

It is quite clear that, if the plane of the heliograph mirror is at such an angle to the straight line joining the centres of the sun and of the heliograph mirror as is shown in the lower of the two positions indicated in the diagram, a larger number of the rays from every point on the sun's surface fall on, and are reflected by, the heliograph mirror than in the case when that angle is such as is shown in the upper of the two positions in the diagram.

Yet in either case each part of the mirror receives and reflects a cone of rays of precisely the same dimensions, viz., a cone with the sun's face for its base and the distance of the sun from the earth for its height.

Consequently the width of the reflected beam at any considerable distance from the mirror is the same in both cases; but, as more rays are reflected in the lower case than in the upper case, the intensity of illumination produced at a given considerable

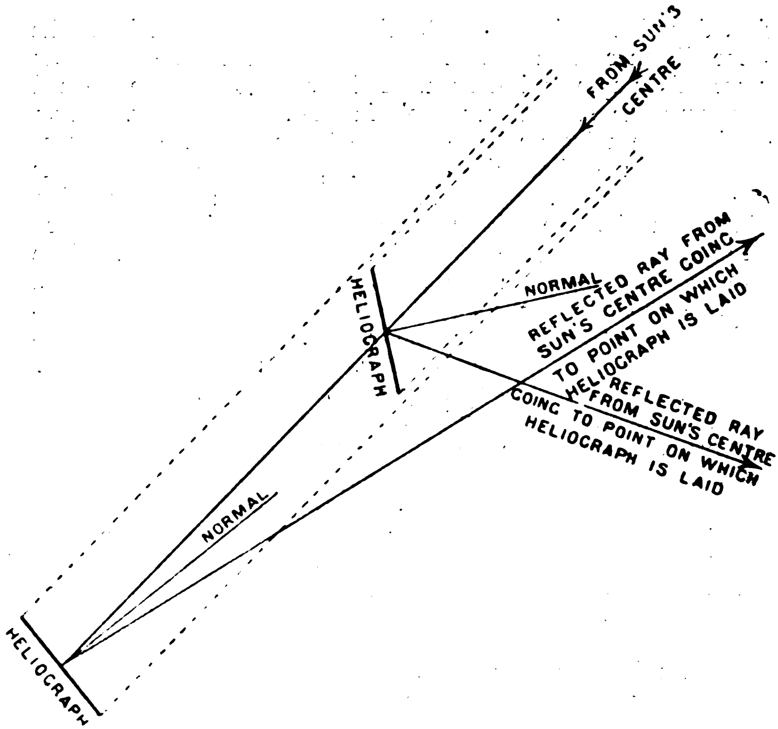

Fig. 69.

distance from the mirror is greater in the lower case than in the upper case. In fact the intensity of illumination produced by reflection from a plane mirror of any given area, at a considerable distance from the mirror, is that due to the area representing the projection of the mirror's surface on to a plane at right angles to the straight line joining the centres of the sun and the mirror; or, since these two areas are equal, is the same as that due to the area represented by the projection of the mirror's surface on to a plane at right angles to the line joining the centre of the mirror and the point the heliograph is laid on. *Vide* figure below.

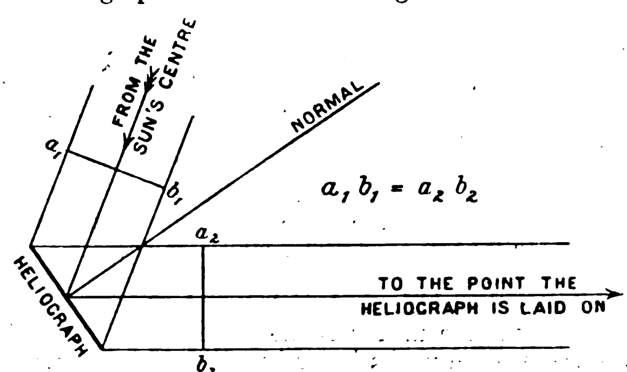

Fig. 70

Next consider the influence, on the illumination produced by the reflected rays on a plane at right angles to their direction, of varying the distance of that plane from the mirror, while keeping it always considerable.

Influence o range of point heliograph is laid on.

Assuming, which is not actually the case, that the reflected light passes through the intervening air without any absorption of light, it is clear that the illumination produced on a plane at right angles to the axis of the cone of reflected rays from any part of the heliograph mirror falls off as the square of the distance between that plane and the heliograph mirror: for the area of the base of the cone increases as the square of that distance, while the whole number of rays of light included in the cone remains the same.

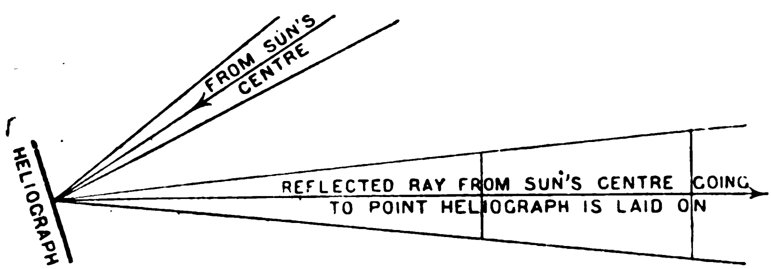

Fig. 71.

And this is true of every cone of rays reflected from any part of the mirror.

Hence, subject to the condition (which, as said before, is not quite correct) that the air absorbs no light, the intensity of the illumination produced by the beam reflected from the heliograph mirror on a plane at right angles to the direction of the reflected beam falls off as the square of the distance from the mirror of that plane.

In actual practice, through the absorption of light by the air, the intensity at any range is somewhat less than the above law based on the hypothesis of non-absorption would indicate. The law regarding the variations in the amount of absorption with varying ranges is rather complicated, and it is not proposed to consider it here.

The width of the beam obviously increases in exact proportion to the increase in the range.

To enable us to take full advantage of the consideration of the case of light projection with the heliograph as an introduction to the optics of electric light projection, it is desirable to consider what would happen in certain cases which do not actually arise with the heliograph.

Influence of distance of source of light from the mirror.

Thus suppose the sun, *i.e.* the source of light, was further oft from the earth than it is.

Clearly each part of the heliograph mirror would receive and reflect a cone of rays with the same base as when the sun was nearer, but with a greater height than in that case. Hence at any given considerable distance from the mirror the width of the beam

of light would be reduced as the distance of the sun from the mirror was increased, the former being inversely proportional to the latter. The intensity of illumination produced at the given distance from the mirror would not of course be affected by the change in the distance of the sun from the mirror.

Another way of looking at the matter is as follows :—

As the sun's distance from the heliograph mirror is increased, fewer of the rays sent out from any part of the sun's face fall on the heliograph mirror. But on the other hand the area illuminated at any given considerable distance by the reflected beam of light is reduced in the same proportion. Consequently the intensity of illumination produced by the reflected beam at any considerable distance is unaltered.

It is of course clear that if the distance of the sun from the earth is supposed to be increased and other things remain the same, the distance from the mirror at which the exact superposition of all the cones of rays of light from various parts of the mirror can be assumed to take place is also increased.

Influence of variation of the brightness of the source of light.

It is quite clear if the brightness, sometimes called the "intrinsic brilliancy," of the sun, the source of light, is varied, while all other things remain the same, then the intensity of illumination produced by the reflected rays at a given considerable distance will vary in a precisely similar manner. The width of the beam will not be in any way affected.

If one part of the source of light, say the top, is less bright than the rest, then, if a cross section of the reflected beam be taken at a considerable distance from the mirror, it is clear from what has already been said that the lower part of the cross section of the beam will be less illuminated than the rest, the shape of the less illuminated portions of the source and of the less illuminated portions of the cross section of the reflected beam exactly resembling one another, and the reduction in the brightness of the source and the intensity of the illumination of the affected part of the cross section also corresponding exactly.

Influence of shape of source of sight.

Suppose the sun, the source of light, were not spherical.

All parts of the heliograph mirror see exactly the same view of it whatever its shape, since the mirror is small compared with the distance of the sun, the source of light, from the earth. This view will not, of course, correspond to the true shape of the source of light, but to that shape foreshortened somewhat in consequence of any departure from directness in the view of the source of light seen from the part of the mirror under consideration. (When the distance of the source of light from the mirror is very great compared with the size of the source of light, this view becomes the projection of the source of light, whatever its shape, on to a plane passing through its centre and at right angles to the straight line joining the centre of the mirror and the centre of the source of light.)

Hence each part of the mirror receives and reflects a pyramid of rays whose base depends for its shape on the shape of the source of light as seen from the centre of the mirror, and whose height is the distance of the sun's centre from the earth.

All parts of the surface of the mirror, as already stated, may be regarded as in exactly the same case as the central part.

Each part of the mirror receives and reflects then such a pyramid of rays of light. At a considerable distance from the mirror all the pyramids of light are practically exactly superposed, the mirror being a small one. Consequently at any considerable distance from the mirror, the beam thrown from the heliograph would be a pyramid with its apex at the mirror and its base an exact (but inverted) reproduction of the form of the source of light as seen from the centre of the mirror.

Summary of results.

Summing up the conclusions we have arrived at so far, we find that—given a plane mirror, small in size in comparison with its distance from the source of light—we get the following rules for the results produced by the reflected rays of light on a plane at right angles to the straight line joining the centre of the mirror and the point towards which the reflected rays are directed, if that plane be at any considerable distance from the mirror:—

1. The intensity of illumination depends on—

(*a*) The intrinsic brilliancy of the source of light.

It varies directly as the intrinsic brilliancy of the source of light.

(*b*) Size (not the shape) of the plane mirror.

It varies directly as the area of the plane mirror.

(*c*) The obliquity of the plane mirror to the direction of the central (incident or) reflected ray.

It varies directly as the cosine of the angle of the mirror's departure from direct opposition. Or in other words, in reckoning the size of the plane mirror account must only be taken of the area of its projection on to a plane at right angles to the central (incident or) reflected ray.

(*d*) The distance from the plane mirror to the plane mentioned above, viz.: that plane the results on which we are considering.

It varies inversely as the square of this distance.

The intensity of illumination does not depend on—

(*a*) The size or shape of the source of light.

(*b*) The obliquity of the principal face of the source of light to the direction of the central incident ray.

(*c*) The distance of the source of light from the mirror.

(*d*) The shape (not the size) of the plane mirror.

2. The area illuminated depends on—

(*a*) The size (not the shape) of the source of light.

It varies directly as the area of the source of light.

(*b*) The obliquity of the principal face of the source of light to the direction of the central incident ray.

It varies according to a law which states that in reckoning the size of the source of light, account must only be taken of the foreshortened view of it seen from the centre of the mirror.

(*c*) The distance of the source of light from the mirror.

It varies inversely as the square of this distance.

(*d*) The distance from the plane mirror to the plane mentioned above, viz.: that plane the results on which we are considering.

It varies directly as the square of this distance.

The area illuminated does not depend on—

(*a*) The intrinsic brilliancy of the source of light.

(*b*) The size of the plane mirror.

(*c*) The shape of the plane mirror.

(*d*) The obliquity of the plane mirror to the direction of the central (incident or) reflected ray.

(*e*) The shape of the source of light.

3. The shape of the area illuminated depends on—

(*a*) The shape of the source of light.

It resembles the foreshortened view of the shape of the source of light seen from the centre of the mirror, but inverted.

(*b*) The obliquity of the principal face of the source of light to the direction of the central incident ray.

It resembles the foreshortened view of the shape of the source of light as seen from the centre of the mirror, but inverted.

The shape of the area illuminated does not depend on—

(*a*) Anything else except 3 (*a*) and 3 (*b*) above.

Light Projection of Electric Light.

Introductory remarks.

Turning now to the subject of Electric Light Projectors, it will in the first place be necessary to consider the nature of the source of light.

The source of practically all the light from continuous current arc lamps—and these alone are suitable for electric light projectors, alternating arcs being ill adapted for such purposes—is the crater of the positive carbon. This crater is generally speaking somewhat irregular in its shape in consequence of imperfections in the burning of the arc; nor does it present exactly the same shaped view to all parts of the reflector of an electric light projector. As seen from any part of the reflector the view presented is generally speaking roughly equivalent to a direct view of an elliptical source of light, the ellipse being the foreshortened view seen from that part of the reflector of a circle whose circumference corresponds with the lip of the crater. Of course from certain parts of the reflector the tip of the negative carbon may cut off the view of part of the crater. More will be said of such a state of things further on.

The source of light may be taken as uniformly bright. In actual practice, from imperfections in the burning of the arc, or want of homogeneousness in the carbons, this is not nearly always the case; but it is the ideal after which we strive, and which is often attained for a time at any rate. Moreover, any departure from this condition takes place at one time in one part of the crater and at another in another part; consequently it is better to consider

the source of light as uniformly bright and to regard the cases where this is not true as abnormal. It will be quite easy after studying the case of normal burning to see what the effect of abnormal burning on the light projection will be.

Again, *with properly burning arc lamps* the area of the crater in the positive carbon may be taken as directly proportional to the current flowing along the carbons. It is true that the ratio of the amperes to the square centimetres of crater surface can be varied, *e.g.* variations in the nature of the carbons used can produce such a result; but there is a certain value for this ratio which is found to be the best, and it is this value which is assumed to be implied in the condition specified for above, viz. *with properly burning arc lamps.*

What the exact figure for this value of the above ratio is cannot be definitely stated. Various experiments have given various results. Perhaps 5 square mm. of crater surface per ampere is not far from the mark.* Some authorities place this figure as low as 2 square mm. of crater surface per ampere.

Also the intrinsic brilliancy of the crater surface, *i.e.* the amount of light per square cm. of crater surface given off in a direction normal to that square centimetre of crater surface, with properly burning arc lamps, is constant.

Here also an exact value of the constant, *i.e.* the intrinsic brilliancy of the crater surface, cannot be definitely stated. Various experiments have given various results. It appears to be below 200 candles per square millimetre; some experiments show it as low as 70, while others place it as high as 170 candles per square millimetre. Its value depends on the nature of the carbons used. 120 candles per square millimetre of crater surface may perhaps be taken as an average value.

In any case the light from the crater of the electric arc lamp and from a standard candle are so different in colour that not much meaning can be attributed to any attempt to express the value of the intrinsic brilliancy of the crater by any one value in candles. All that concerns us here, however, is the fact that the intrinsic brilliancy for properly burning arc lamps is constant. So long as the arc lamp is burning properly it does not depend on the current flowing in the carbons, although, of course, the condition of proper burning postulates that larger carbons are used with a larger current. Every square millimetre of the crater surface of a 10-ampere arc lamp is just as brilliant as, and no more brilliant than, every square millimetre of the crater surface of a 160-ampere arc lamp, if each lamp is properly burning, while the diameter of the crater of the 10-ampere arc lamp is, of course, only about a quarter the size of that of the 160-ampere arc lamp.

It will no doubt have been observed that all these statements regarding the source of light in electric light projectors are only given as approximations. It must not be thought that on that account they are not of much value. On the contrary, practically they may be all accepted as true.

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* This corresponds to about 3 square mm. of carbon section per ampere for the positive carbon, to allow for waste of carbon near the crater.

Case of a 90 cm. diameter 45 cm. focal length paraboloid eflector.

Let us now commence the consideration of an actual service electric light projector, viz. that whose reflector is metallic (without any glass), is a paraboloid in shape, has a diameter* of 90 centimetres (about 3 feet), and a focal length of 45 centimetres (about 18 inches). Such a reflector, made of copper plated with palladium, is used for arcs up to 120 or even 150 amperes, the centre† of the crater being, of course, placed at the focus of the reflector.

We will consider that a horizontal arc lamp is being used with this projector, and that everything is so arranged as to produce proper burning of the arc.

That diameter of the crater which is not foreshortened will, as seen from any part of the reflector, subtend an angle of about 3 degrees when a 120-ampere arc is being used. This angle depends, of course, on the nature of the carbons used, and on the amperage of the arc employed, and is somewhat less for parts near the edge of the reflector than for parts near the centre.

The form of this reflector, a paraboloid, is, of course, such that all rays of light starting from the focus will after reflection be projected in a direction parallel to the axis of the paraboloid.

Now, consider the paraboloid as being made up of an infinite number of equal infinitesimally small plane mirrors, the plane of each of which is at right-angles to the normal to the surface of the paraboloid at the centre of the infinitesimally small plane.

Each of these small plane mirrors will be under circumstances exactly similar to the case already considered of the plane heliograph mirror.

For the latter mirror (the heliograph), relatively speaking, the distance of the source of light from the mirror was infinitely great, the size of the source of light was infinitely great, the size of the mirror was finite; while for the former mirror (the element of the paraboloid), relatively speaking, the distance of the source of light from the mirror is finite, the size of the source of light is finite, the size of the mirror is infinitesimally small. Relatively, then, in the two cases the various dimensions involved are of the same order of magnitude. Consequently, at any great distance from the little mirror forming the element of the paraboloid, and much more at any distance from the paraboloid great compared with the diameter of the latter, we shall get the following effects produced by the action of that small elemental mirror, viz., a cone of rays will be projected from the surface of the small elemental mirror with its axis parallel to the axis of the paraboloid, since practically no error is involved in regarding the straight line joining the centre of the small elemental mirror to the focus of the paraboloid as the axis of the cone of incident rays, and with its base (except in the case of parts of the reflector where the negative carbon shuts out part of the view

* By diameter is meant the diameter of the circle formed by the bounding edge of the front of the paraboloid. This is sometimes called the diameter of the aperture of the reflector.

† By "the centre of the crater" is meant the centre of the circle whose circumference corresponds with the lip of the crater.

of the crater—these parts will be considered later) an ellipse, the dimensions of whose major axis depends partly on the diameter of the crater and partly on the distance the small elemental mirror is from the centre of the source of light, and the dimensions of whose minor axis depends partly on the foreshortened view of the diameter of the crater as seen from the small elemental mirror, and partly on the distance of that mirror from the centre of the source of light. The intensity of illumination over the base of this cone of rays will be everywhere the same, and will be that due to the intrinsic brilliancy of the crater, and to the size of the small elemental mirror, reduced, however, in proportion to the obliquity of the small elemental plane mirror to the central (incident or) reflected ray.

In other words, the intensity of illumination over the base of the cone of rays will be such as would arise from the intrinsic brilliancy of the source multiplied by the projection of the area of the small elemental mirror on to a plane at right-angles to the axis of the paraboloid.

Now, remember that every part of the paraboloid all round the circumference of a circle passing through the part already mentioned, and formed by the section of the paraboloid by a plane at right-angles to its axis, is in exactly the same case, and sends out exactly the same sort of cone of rays, except that for the parts of the paraboloid separated by one-quarter of the circumference of the circular section of the paraboloid, the positions of the major and minor axes of the base of the cone of rays will have mutually changed places, and for any intermediate part these axes lie in an intermediate position.

Also remember that at great distances from the reflector, such as 1,000 yards, the diameter of the reflector, 90 cm., or about 3 feet, vanishes in comparison with the dimensions of the base of the cone of rays from any part. For the outer part of the paraboloid does not approach nearly to the plane at right-angles to the axis of the paraboloid passing through the focus, and consequently the angular width of the minor axis of the elliptical base of the cone of rays reflected from no part of the reflector becomes so small as to interfere with this. Consequently at such great distances we may consider that we get the apex of every cone of rays sent from every part of the reflector as originating from the apex of the paraboloid.

Hence, of the paraboloid, every zone of elemental width, such as we have described above, produces at a great distance from the reflector a cone of rays which may be regarded as emanating from the apex of the paraboloid, and with a *circular* base.

This base consists of a central circle of uniform illumination, whose diameter is determined by the angular width of the foreshortened view of the crater's diameter seen from any part of the zone, and then, outside this, a ring of illumination, the diameter of whose outer circumference is determined by the angular width of the unforeshortened diameter as seen from any part of the zone; the illumination in this ring is not uniform, but falls off gradually but regularly from a value at the inner circumference

of the ring equal to the illumination of the central uniformly illuminated circle of the base of the cone, to nothing at the outer circumference of the ring.

And the value of the illumination of the central (most illuminated) part of the base of the cone is that due to the product of the intrinsic brilliancy of the crater multiplied by the area of the projection of the zone on to a plane at right-angles to the axis of the paraboloid.

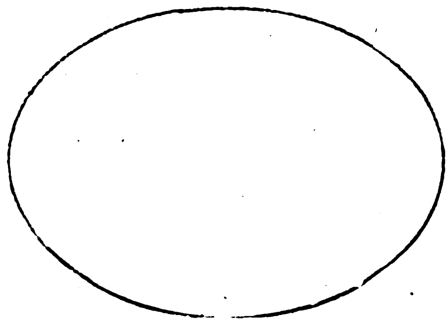

Fig. 72.—Base of cone of rays reflected from a part of the reflector near its edge.

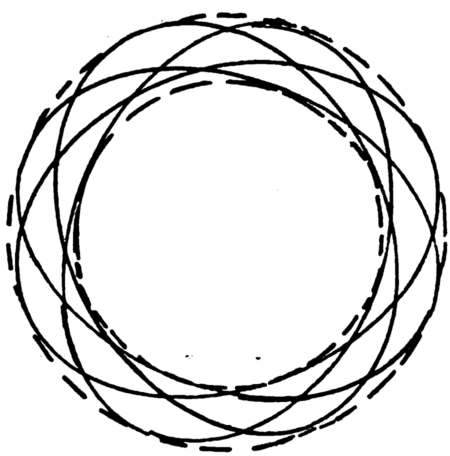

Fig. 73.—Base of cone of rays due to corresponding zone of the reflector.

Now, supposing for the present that there was no obscuration at any part of the paraboloid of part of the crater by the negative carbon, we can clearly, then, regard the paraboloid as made up of a series of such zones as that already described.

Each such zone will produce a cone of rays such as already described, but neither the angular width of the central uniformly illuminated circle, nor the angular width of the outer less and non-uniformly illuminated rings of the bases of these cones due to successive zones will be identical for all zones.

These angular widths, and consequently the corresponding

diameters of cone bases, will be least for the parts of the paraboloid nearest its edge, and greatest for the parts of the paraboloid at its centre.

All such cones due to zones of the paraboloid may, of course, be regarded as superposed, and as emanating from the apex of the paraboloid when considering the effect of the illumination at a great distance from the reflector.

There will, therefore, result from the whole paraboloid a cone of rays emanating from its centre, with the centre of the cone of rays coincident with the axis of the paraboloid, with a base consisting of a central part uniformly illuminated,* and a ring outside this central part not uniformly illuminated, but gradually falling in illumination from a value equal to the illumination of the central uniform illumination at its inner circumference to nothing at its outer circumference.

The angular width of the diameter of the central uniformly-illuminated portion of this base will be that due to the most fore-shortened view of the crater's diameter seen from a part of the reflector at the edge of the paraboloid, and the angular width of the circle constituting the outer or extreme boundary of the cone of rays, where the value of the illumination just vanishes, will be that due to the unforeshortened view of the diameter of the crater seen (or supposed to be seen) from the apex of the paraboloid.

Moreover, it is evident from what has gone before that the value of the illumination of the central uniformly illuminated part of the cone-base will be that due to the intrinsic brilliancy of the crater multiplied by the projection of the whole reflector on to a plane at right angles to the axis of the paraboloid.

It will also be evident that the value of the illumination produced with this paraboloid reflector on a plane at right angles to the axis of the paraboloid, at considerable distances from the reflector, will vary inversely as the square of that distance.

Or, in symbols—

If D be the diameter of the paraboloid reflector,

R be the considerable distance from the paraboloid reflector to the plane at right angles to its axis, the illumination on which is being considered,

i be the intrinsic brilliancy of the source of light,

I be the intensity of illumination produced on the plane mentioned above at places where this illumination is a maximum (*i.e.*, in the central part of the beam),

we have

$$I \propto \frac{i\,D^2}{R^2}\,.$$

Observe that neither the focal length nor the value of the current employed appear in this expression for I. They affect the width of the beam. The focal length affects not only the total width, and the width of the central uniformly illuminated part where the illumination is greatest, but also the relative widths of

* Sometimes called the "central spot" of the beam.

these two. The value of the current employed affects not only the total width of the beam, but also the width of the central uniformly illuminated part where the illumination is greatest; but it does not affect the relative values of these two widths.

Now, it is the central uniformly illuminated part of the beam that is regarded as the really useful portion.

The outer non-uniformly illuminated portion is regarded as rather a drawback than otherwise, forming, as it does, a sort of luminous haze between the observer and an object in the best part of the beam.

Consequently, such a value is given to the focal length, relative to the diameter, that the width of the central uniformly illuminated part may be about a maximum. But the *exact* value of this ratio to produce a maximum is not actually employed, because, where there is no obscuration at any part of the paraboloid* of part of the crater by the negative carbon, it is considered better to use a slightly longer focal length in order to reduce the width of the ring of non-uniform illumination surrounding the central uniformly illuminated part, (the width of this ring falling off then much more rapidly than the width of the central uniformly illuminated part), and when there is obscuration at parts of the paraboloid of part of the crater by the negative carbon, it is considered necessary to use a shorter focal length in order to reduce the influence of this obscuration, as will be explained presently when considering the effect it produces.

These conditions are fulfilled in the case of paraboloids of 90 cm. diameter, by a focal length of about 65 cm. where using such a description of arc lamp that there is no obscuration by the negative carbon, and by a focal length of about 42 cm. to about 45 cm. where using such a description of arc lamp that such obscuration exists.

The curves shown in Plate VIII illustrate the influence of the ratio of the diameter of the reflector to its focal length on the composition of the beam when there is no obscuration.

It would not, of course, be practically possible, even if it were optically desirable, to reduce the focal length much below the lower figures given above, as the heating effect produced on the paraboloid would be so great as to damage it, unless, of course, the strength of the current used were considerably reduced. But since reducing the current reduces the width of the beam, we should soon find, if we reduced the current much, that to illuminate a given width at a given range required too many projectors to be practicable, either from the point of view of the first cost of projectors, or of the staff required for their manipulation. These considerations of cost also prohibit the use of very long focal lengths.

We have still to consider the influence, such as it is, of the obscuration by the negative carbon of part of the crater in the positive carbon as seen from certain portions of the paraboloid reflector.

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* This of course can never be the case with horizontal arc lamps, but may with inclined arc lamps.

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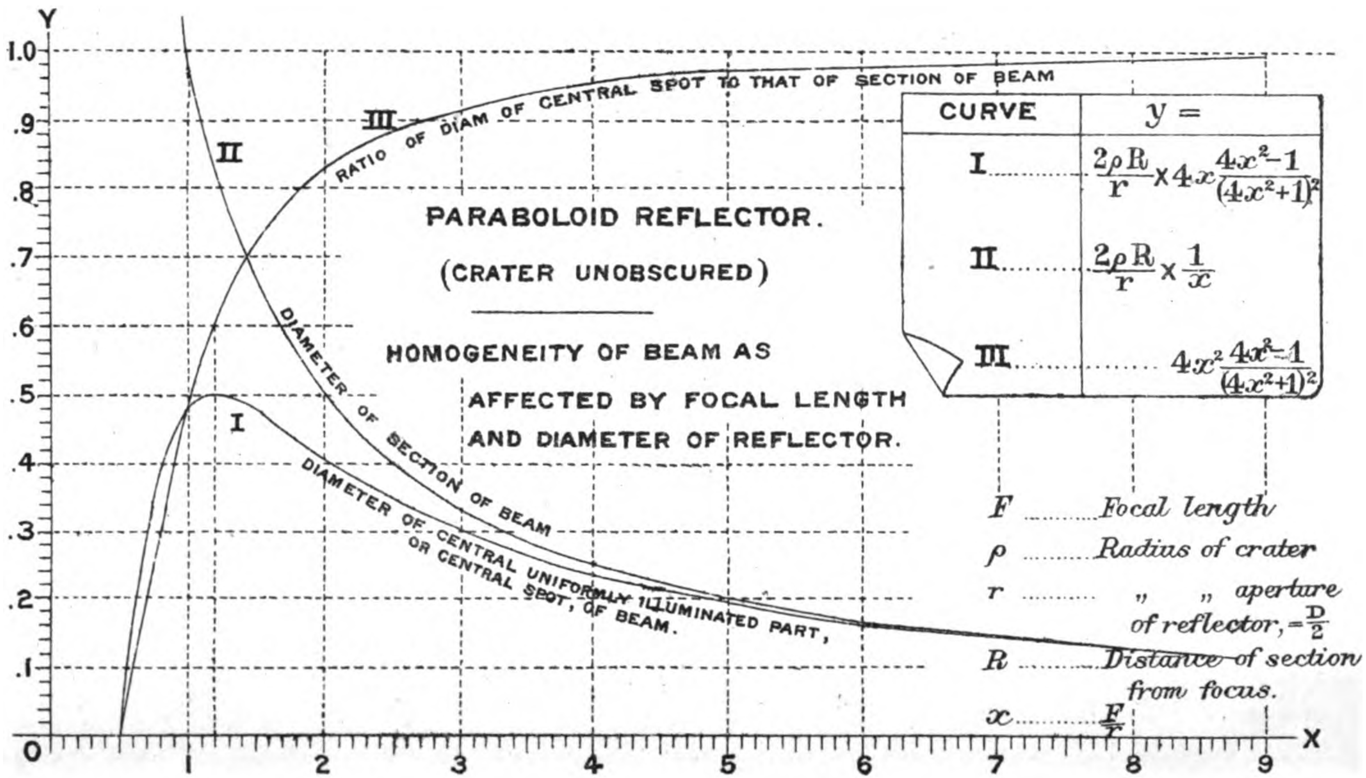
PLATE VIII.



It is assumed that the foreshortened view of the diameter of the crater seen from any point P is $2\rho \cos \varphi$, Where φ is the angle between the straight line joining P to the focus and the axis of the paraboloid.

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It is clear that with horizontal arc lamps any part of the reflector near the apex of the paraboloid will only see a lune-shaped view of the crater.

Let us first consider a part of the reflector which, while it sees a lune-shaped view of the crater, can see the centre of the crater.

Any such part of the reflector reflects a pyramidal beam of light with the base of the pyramid exactly resembling this lune-shaped view, but inverted; moreover, the ray in this pyramid

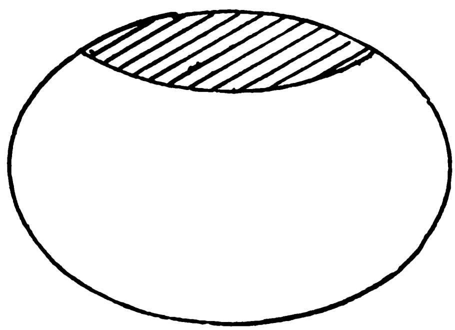

Fig. 74.—Base of pyramid of rays reflected from a part of the reflector where there is slight obscuration.

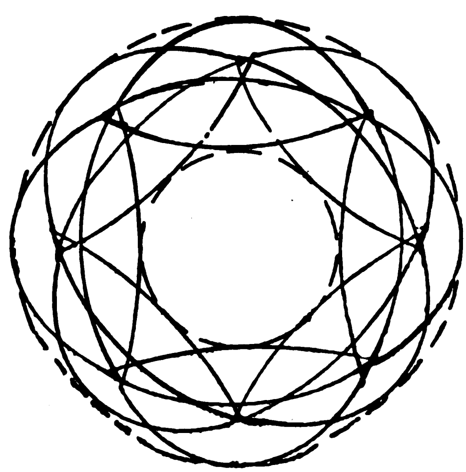

Fig. 75.—Base of pyramid of rays due to corresponding zone of the reflector.

joining the centre of the part of the reflector to the focus of the paraboloid is reflected in a direction parallel to, and practically (when considering effects at considerable distances from the paraboloid) coincident with the axis of the paraboloid.

Considering the effect produced by all such exactly similar pyramids of rays reflected from all parts of the zone of the paraboloid corresponding to the part just dealt with, we see that we shall get from them at any considerable distance from the paraboloid a circular-based cone of light, with its apex at the apex

of the paraboloid, with its axis coincident with that of the paraboloid, and with the illumination over its base uniform in and of a maximum value in the central circular part of the base, and then over an outer ring dying away from the value of the illumination in the central portion to nothing at the outer circumference.

Moreover, all such zones as that just described will together produce as their resultant a circular-based cone of light with its apex at the apex of the paraboloid, with its axis coincident with the axis of the paraboloid, and the illumination over its base a maximum at the centre of the base, and falling away gradually to nothing at the circumference of the base.

Next let us consider a part of the reflector which sees a lune-shaped view of the crater but cannot see the centre of the crater. Any such part of the reflector reflects a pyramidal beam of light with the base of the pyramid exactly resembling the lune-shaped view of the crater seen by that part of the reflector, but inverted;

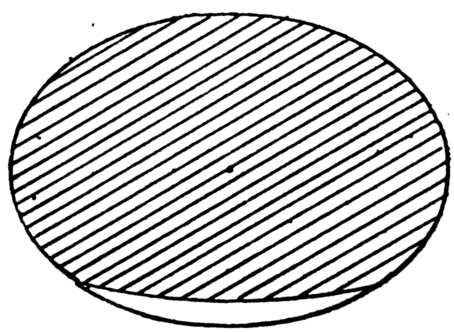

Fig. 76.—Base of pyramid of rays reflected from a part of the reflector where there is much obscuration.

moreover, every ray in this pyramid will be reflected in a direction only departing from parallelism to, and (when considering effects at considerable distances from the paraboloid) practical coincidence with, the axis of the paraboloid to exactly the same angular amount as it departs from coincidence with the straight line joining the centre of the part of the reflector to the focus of the paraboloid.

Considering the effect produced by all such exactly similar pyramids of rays reflected from all parts of the zone of the paraboloid corresponding to the part just dealt with, we see that we shall get from them, at any considerable distance from the paraboloid, a funnel-shaped beam of light; the apex of the funnel being at the apex of the paraboloid; its axis coincident with the axis of the paraboloid; its base being a circular ring, and the illumination over its base being nothing at the inner and outer circumferences of the ring, and rising to a maximum for a circle lying between these diameters.

Moreover, all such zones as that just described will together produce as their resultant a circular based cone of light, with its

apex at the apex of the paraboloid, its axis coincident with the axis of the paraboloid, and the illumination over its base of the value nothing at the centre and at the circumference of the base, and rising to a maximum for a circle lying between the centre and the circumference.

Any paraboloid reflector, then, when used with a horizontal arc lamp, will produce a conical beam of light which may be regarded as being made up of three parts, viz. :—

1. A conical beam from the parts of the reflector where there is no obscuration.

2. A conical beam from the parts of the reflector where there is some obscuration, but the centre of the crater is not obscured.

3. A conical beam from the parts of the reflector where there is much obscuration, so much that the centre of the crater is included in the obscured portion of the crater.

These cones all have the same axis and the same apex, and the resultant illumination produced on a plane normal to their axes at a considerable distance will be the sum of the illumination due to each of the three parts.

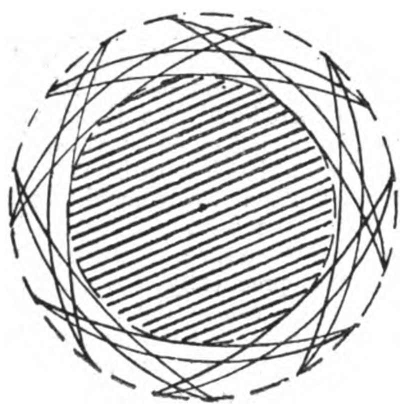

Fig. 77.—Base of funnel-shaped beam of light due to corresponding zone of the reflector.

Now the effect of the obscuration is clearly altogether bad; not only does it decrease the resultant illumination as a whole, but it tends to upset the uniformity of the illumination produced.

In order then to reduce the evils produced, the focal length of the paraboloid is made as small as is consistent with other considerations already mentioned, as under these circumstances the area of the reflector affected by obscuration, and consequently the effect of the obscuration on the resultant beam, is reduced.

In practice the focal length can be, and is, so far reduced that the influence of obscuration may be neglected. It is, however, worthy of note that, in some forms of reflectors, the focal length of the central part of the reflector is made greater than the focal

length of the outer portions in an increasing ratio as the apex of the reflector is approached, in order that, with the centre of the crater placed at the focus of the outer part of the reflector, we may get the straight line joining any part of the reflector where there is obscuration to the focus of that part passing more nearly through the centre of figure of the lune-shaped view of the crater seen from that part of the reflector, thereby reducing somewhat the irregularity of the illumination produced at a distance by the lunes by making the illumination of the base of the cone of rays increase continuously inwards towards its axis, where the illumination is made thus a maximum.

In the early days of projector work, when no satisfactory pattern of automatic arc lamp existed for projectors, hand lamps were used. These were inclined lamps, and when they were properly worked there was no obscuration due to the negative carbon; so the focal length of the reflector was made (for reasons already given) as great as 65 cm. for 90 cm. diameter reflectors.

Considerations of regularity of working and of saving of personnel led to persistent efforts to perfect automatic arc lamps for projectors, and, although no practical success has been achieved with inclined lamps, excellent automatic horizontal arc lamps for projectors have been introduced into the service. As, however, these involve a certain amount of obscuration, the focal length of the more recent reflectors has had to be reduced to 42 to 45 cm. for 90 cm. diameter reflectors. There could, of course, be no optical objection (apart from the matter of irregular burning) to using inclined hand lamps for these short focal-length modern reflectors; but it so happens that practically this cannot be done, as the inclination of the carbons causes the negative carbon holder to foul the body of the projector before the lamp is brought in close enough to the reflector for the crater to be in focus.

Other descriptions of reflectors.

Other descriptions of reflectors besides palladium-faced metallic paraboloids of 90 cm. diameter and 45 cm. focal length exist in the service. They will now be briefly described:—

A large number of silvered glass paraboloids are in use.

They are generally 894 mm. in diameter and 42 cm. in focal length. The glass is about 10 mm. thick. For all practical purposes their optics are identical with those of the metallic paraboloids.

A few of these silvered glass paraboloids are of the 45 cm. focal length.

In the early days of projector work it was not possible to obtain paraboloids either metallic or silvered glass of sufficient accuracy of form.

A few silvered glass reflectors were purchased which were spherical in form. Their focal length was long in order that the difference of curvature between a paraboloid and a sphere might not cause the beam to depart much from the desired concentrated form. These may be regarded as a makeshift.

It will be seen, on reference to Fig. 78, that within certain limits the curve of a parabola does not vary much from that of

SPHERICAL ABERRATION

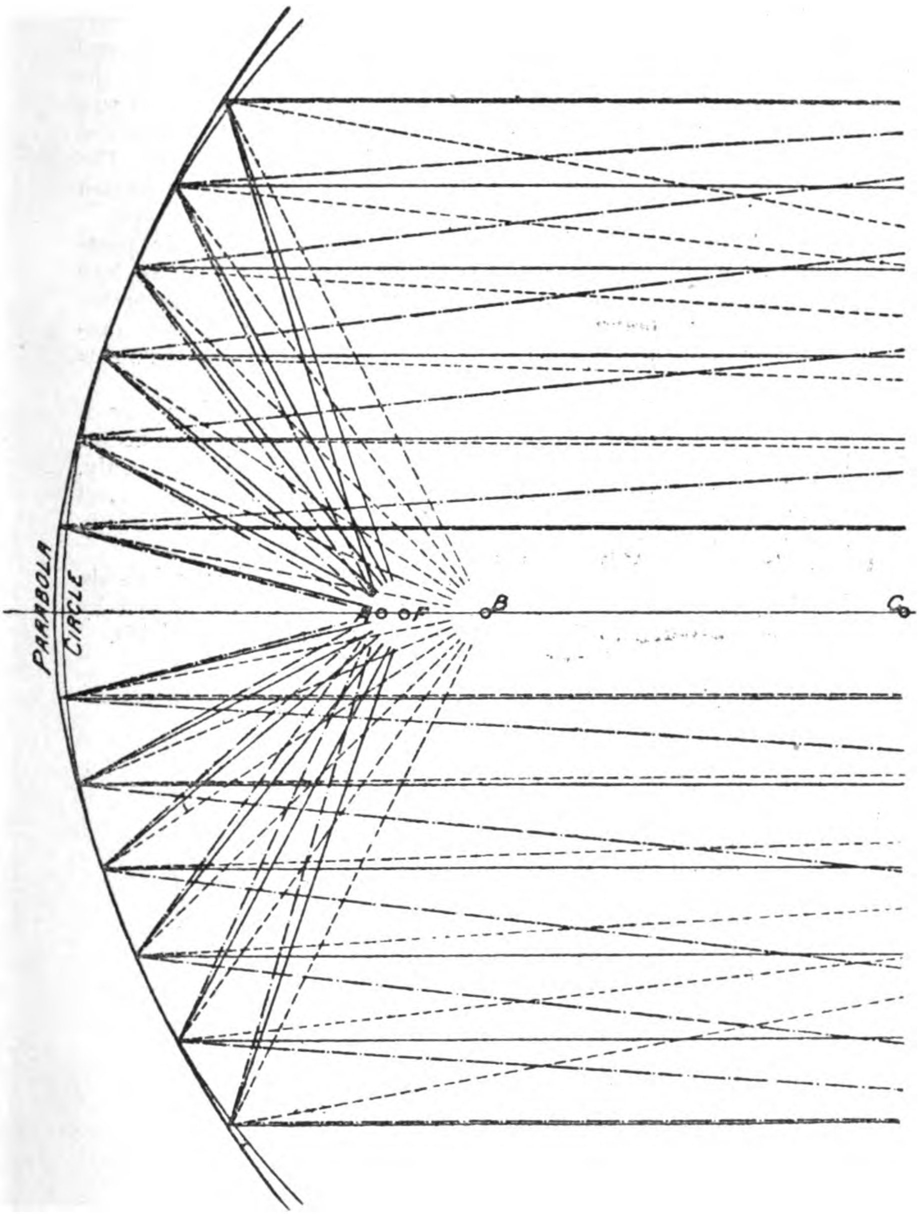

Fig. 78.

a circle. For the central portion of a spherical mirror the focus is at B, a distance from the mirror of half the radius. The rays emanating from a source of light at this point, which strike the peripheral portions of the mirror, are not reflected into a

parallel direction but are rendered convergent, as shown by the plain dotted lines. If now the source of light be moved nearer to the mirror, to a point A, so as to render the peripheral rays parallel, those reflected from a zone between the central and peripheral portions are rendered divergent, as shown by the chain dotted lines. This impossibility of finding a focus to suit all parts of a spherical mirror is due to what is called spherical aberration. F (Fig. 78) is the focus of the parabolic curve. The rays emanating from this point, and their course after reflection from the paraboloid are shown by firm lines.

Some years before it was possible to obtain accurate paraboloids, Colonel Mangin of the French Engineers pointed out how to make silvered glass reflectors with spherical surfaces, accuracy of manufacture being thus rendered possible, which should produce the same result as regards concentration of the beam as arrived at with paraboloids.

Fig. 79 and Plates IX and X show approximately the shape of two reflectors based on this principle, the long focal length reflector being the early form designed for use with inclined lamps only, and the short focal length reflector the more recent form designed to admit of the use of horizontal arc lamps, which, as already stated, can be made automatic.

These Mangin reflectors are heavy compared with the paraboloids, but they give most excellent concentrated beams, considered by some even superior to the concentrated beams from paraboloids.

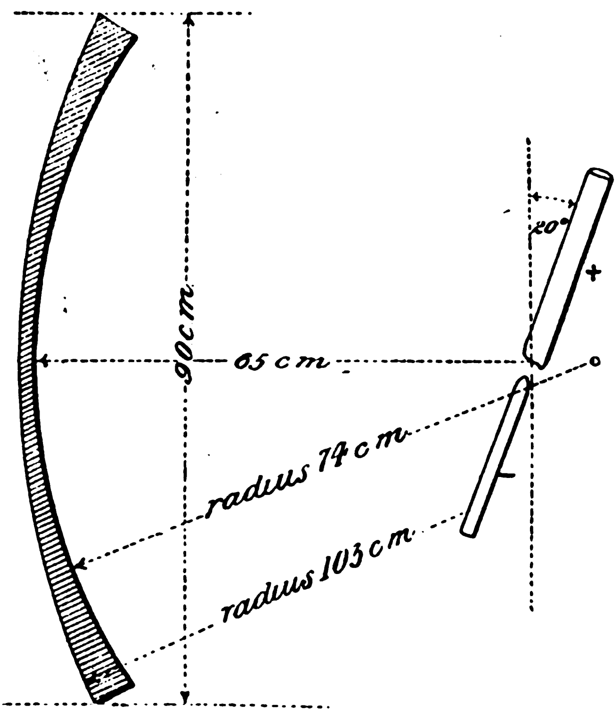

Fig. 79.—Mangin reflector, 90 cm. diameter, 65 cm. focal length.

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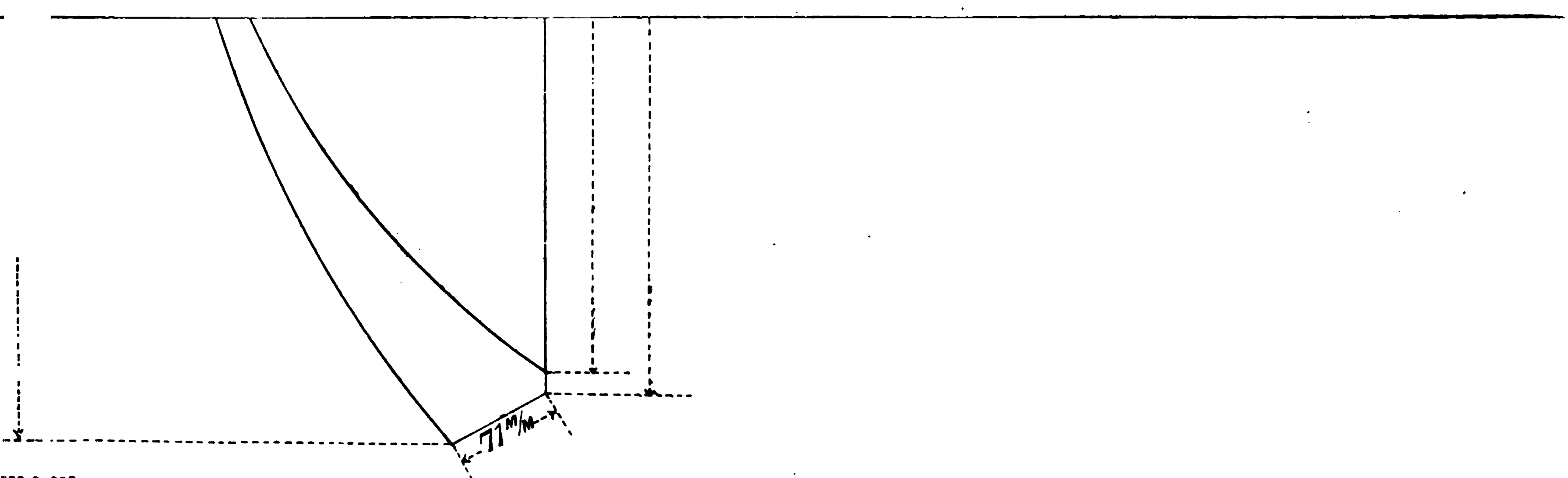

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MEASUREMENTS (

BOTH 90 CENTIMETRES DIAM

	Nº 1. REFLECT
	c/m.
a	96·80
b	89·80
c	00·30
d	07·10
*e	00·68
f	23·30
Approximate values of angles γ	63·0°
β	100·0°

* NOTE. Dimension "e" co
ascertained with
owing to the th
the protective
the silvering.

733 S 1900

In these reflectors the rays from the focus are successively refracted, reflected, and refracted again, as shown in Fig. 80. The spherical aberration is almost perfectly compensated for by the double refraction, but there is some chromatic aberration, causing coloration of the beam at its edges.

MANGIN REFLECTOR.

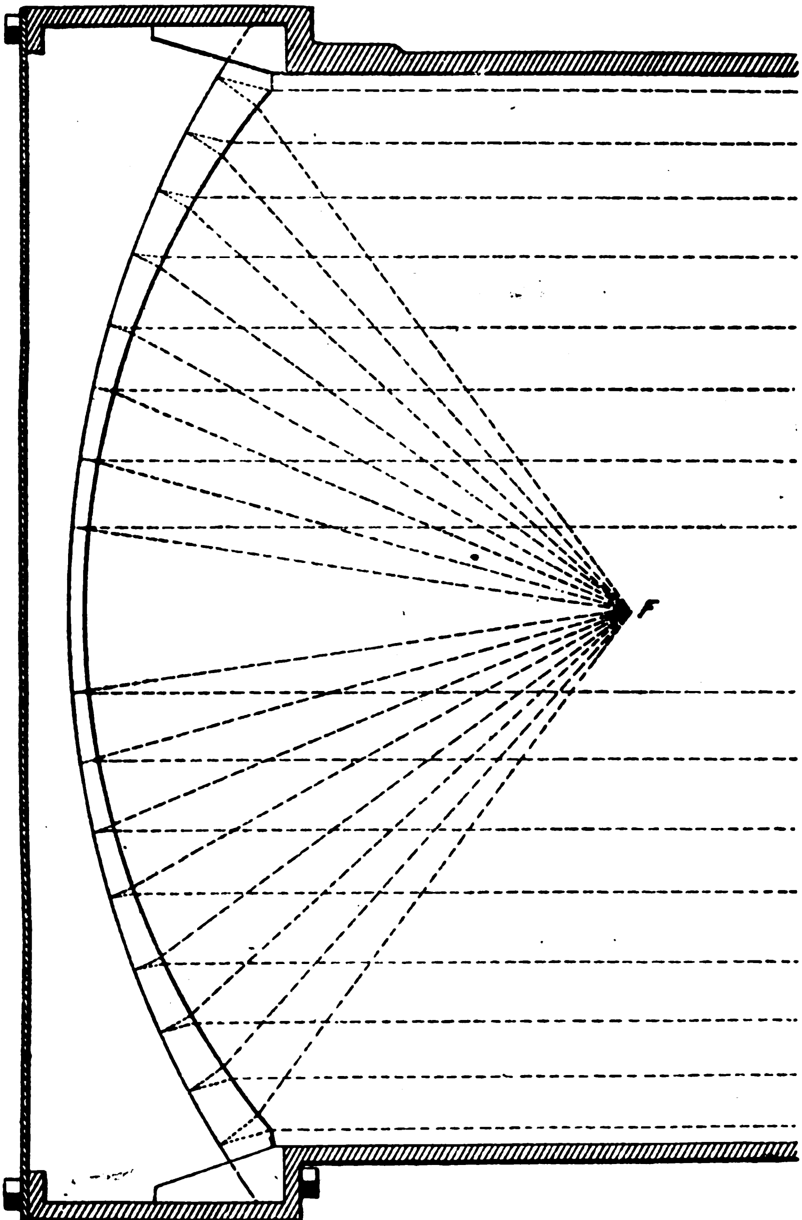


Fig. 80.

Concentrated beams, sometimes called parallel beams, are not, however, always best suited to the conditions under which a demand for projector lighting arises.

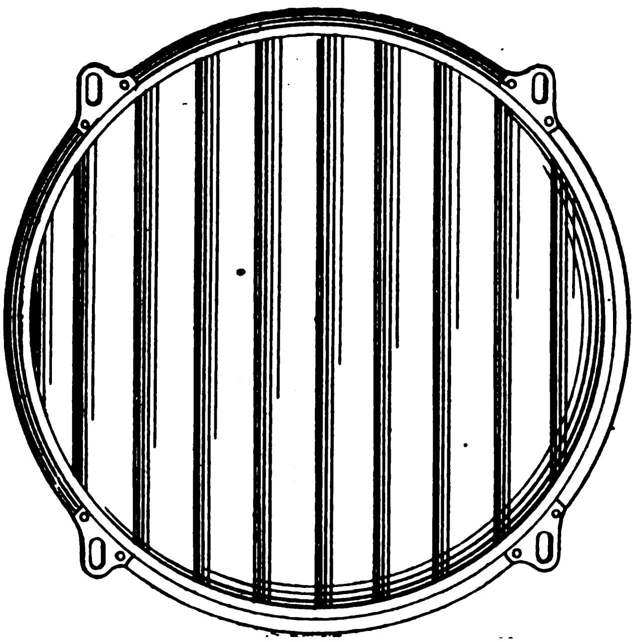
In many cases a beam, concentrated as regards a vertical section through the beam, but uniformly diverged through a considerable angle as regards a horizontal section through the beam, is more suitable.

This was originally arranged for by providing a diverging lens consisting of a series of plano-convex prisms mounted in a gunmetal ring with steel trunnions, for fitting on the front of the projector, which was provided with a reflector designed to produce a concentrated beam. See the sketch Fig. 81.

Diverging lenses of this description designed to produce horizontal divergences of 16°, 30°, and 45°, are service stores.

DIVERGING LENS.

FRONT ELEVATION.



HORIZONTAL SECTION.

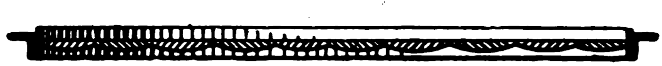


Fig. 81.

The number of these prisms is as under in service diverging lenses :—

For 16° diverging lens ... ... 15 prisms.
For 30° diverging lens ... ... 15 prisms.
For 45° diverging lens ... ... 11 prisms.

NOTE.—The gunmetal ring here shown is not of the service shape as regards its means of attachment to the front of the projector, &c. See Chapter on projectors for detail of service diverging lenses.

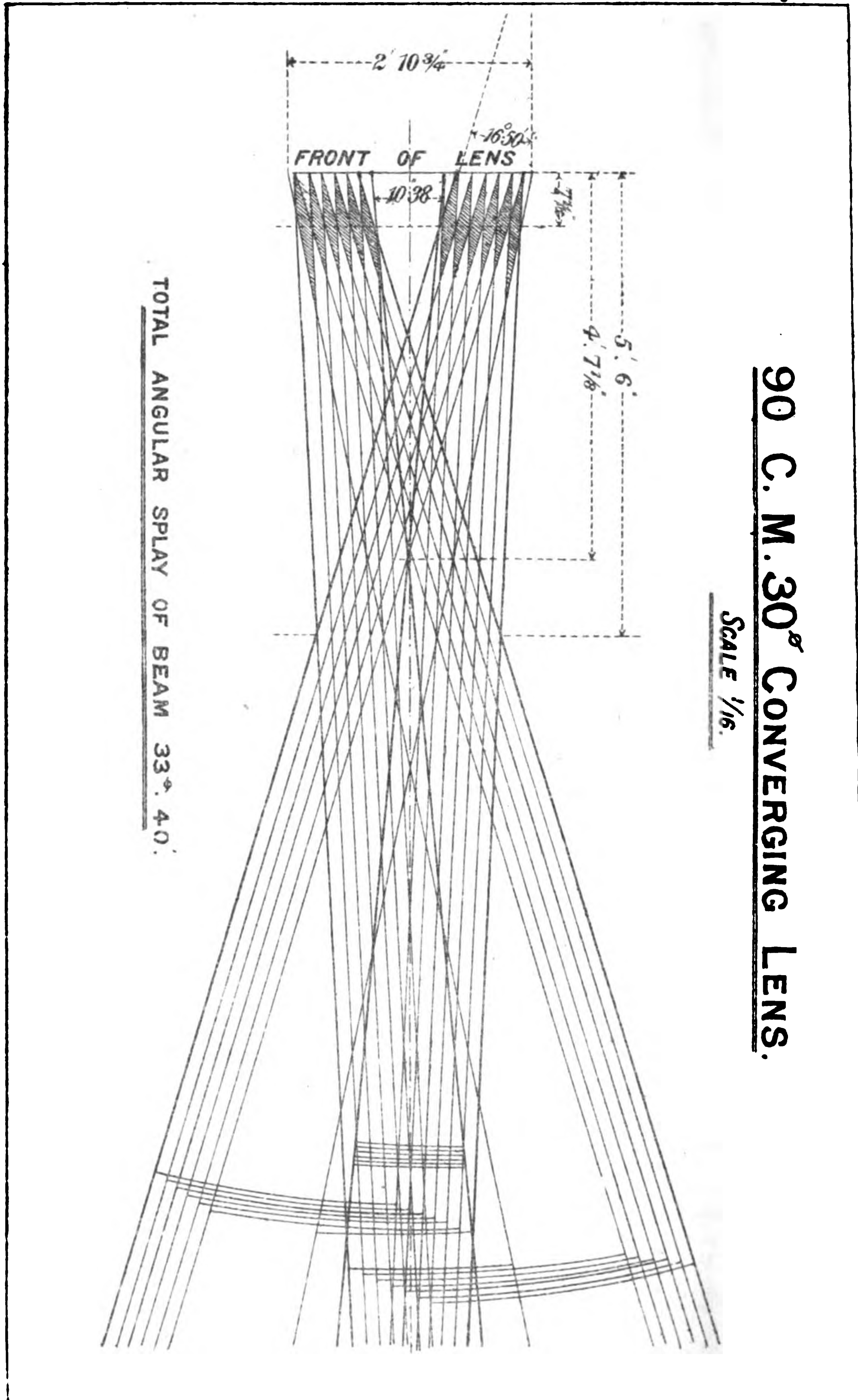


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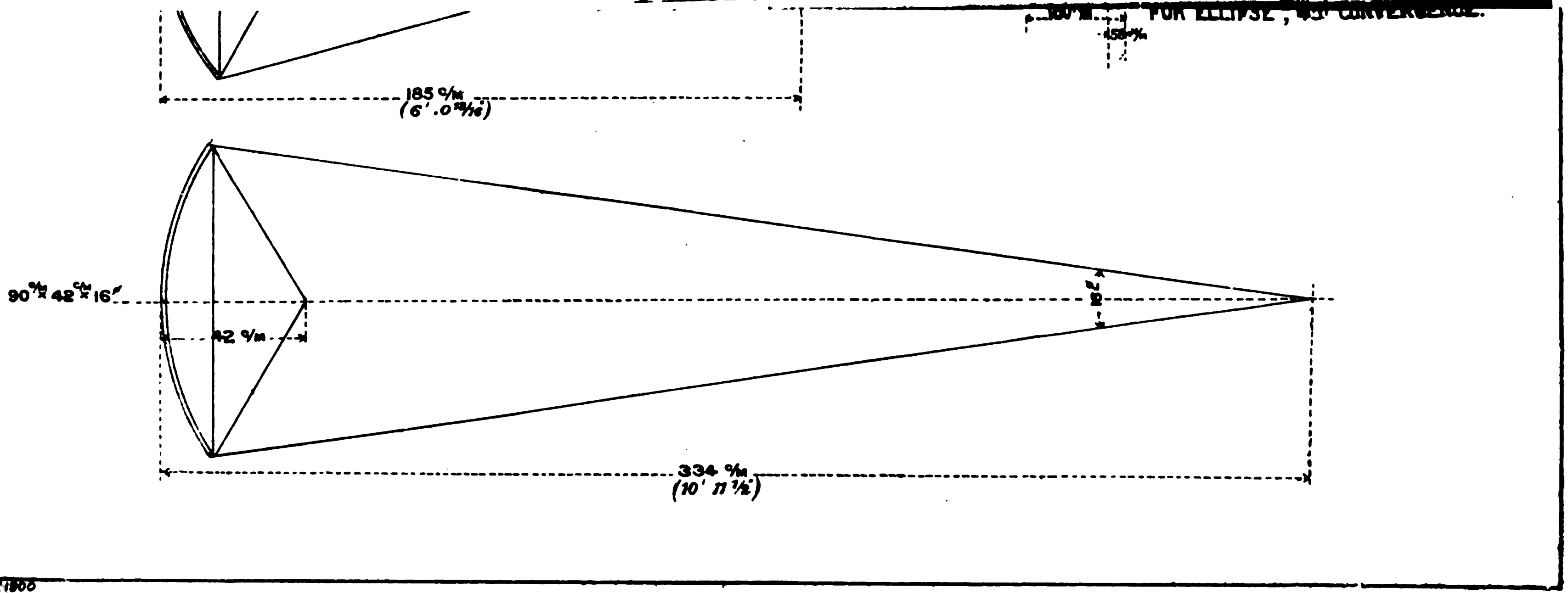
PLATE XII.



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Of late years, when it was found that the horizontally diverged beams would almost always be used as fixed beams, it was desired to devise a method that would admit of great protection from fire for the arrangements producing these beams.

A few so-called " port-hole " lenses were purchased for the Service. Their nomenclature in the Vocabulary of Stores is as under :—

Lenses, 90 cm., converging, 30°.

These are lenses intended to be fitted on the front of a projector fitted with a reflector designed to give a concentrated beam, which converge the beam in the first place. This allows all the rays to pass through a narrow opening in an armour plate, which it is arranged shall lie just in the neighbourhood of the crossing of the converged rays. The beam after convergence diverges to the angle required.

The lens is mounted in a gunmetal frame with iron trunnions of precisely the same dimensions as those in use with the ordinary diverging lenses of 16°, 30°, and 45°, and can be attached to the front of projectors in a similar manner.

The glasses of the lens consist of 15 lenticular strips.

The centre strip is 10¼ inches wide, with a focal length of about 55·125 inches.

The outer strips (7 on either side) have each a focal length of about 7·50 inches, and are so shaped that those of full width (about 1⅝ inches) each throw a beam having itself a splay of 14° 15′, and projected so that its axis makes an angle of 12° 45′ with the axis of the main beam.*

The two outer strips are only 1⅛ inches in width.

The diagram Plate XI shows clearly the manner in which the beam is built up.

The narrowest part of the beam is about 2 feet 2 inches, and at a distance from the lens of about 5 feet 6 inches.

More recently " Parabola-Ellipse " reflectors of silvered glass have been introduced into the Service for giving protected diverged fixed beams.

These reflectors have their vertical section parabolic and their horizontal section elliptical. Their details are shown in Plate XII.

The dimensions of the opening required in the armour plate for these reflectors are as under :—

16° divergence,	3 feet high,	8 inches wide		
30°	,,	,,	4 ,,	For 150 amperes.
45°	,,	,,	2½ ,,	

With the 45° divergence reflector no glass front door can be used on account of the heat at the place of convergence of the rays, which lies just close in front of the projector.

---

* These angles are slightly different from the figures shown here in the case of the lens shown in the diagram. The angles in the case of the diagram are those measured in actual trials of a converging lens.

Approximate Formulæ relating to Electric Light Projection.

The following approximate formulæ relating to electric light projection may prove of use :—

They are based on the assumption that only such of the rays as would contribute to the uniformly luminous central portion of a concentrated beam need be taken into account, and that there is no obscuration of any part of the crater by the negative carbon. A few other assumptions, approximately correct, will be seen from what follows to have been made for the purposes of these formulæ; they are sufficiently obvious not to call for further remark.

Let D = diameter of the reflector.

F = focal length of the reflector.

C = current in amperes in the arc.

R = any considerable range from the projector.

θ = the angle of horizontal divergence for a beam diverged in azimuth only.

Let these be considered as independent variables in the problem of electric light projection.

As a rule, of course, they are not independent variables, for a definite relationship often exists between D and F; also there are limiting conditions, such as risk of damage to the reflector by heat from the crater, which prevents F and C varying independently.

Then since—as a reference to the diagram Plate VIII showing the effect of focal length and diameter of a reflector on the homogeneity of the beam will show—the diameter at range R in the case of a concentrated beam of the central uniformly illuminated area varies as

$$F R \sqrt{C} \frac{16 F^2 - D^2}{(16 F^2 + D^2)^2},$$

we have—

For a Concentrated Beam.

Case A.—Suppose D varies, while F, C, and R remain constant. Then—

Total luminous flux from the crater is constant.

Intensity of illumination at distance of R varies as D^2.

Area illuminated at distance R varies as

$$\frac{(16 F^2 - D^2)^2}{(16 F^2 + D^2)^4}.$$

Total utilised flux of light varies as

$$D^2 \frac{(16 F^2 - D^2)^2}{(16 F^2 + D^2)^4}.$$

Case B.—Suppose F varies, while D, C, and R remain constant. Then—

Total luminous flux from the crater is constant.

Intensity of illumination at distance R is constant.

Area illuminated at distance R varies as

$$F^2 \frac{(16\ F^2 - D^2)^2}{(16\ F^2 + D^2)^4}.$$

Total utilised flux of light varies as

$$F^2 \frac{(16\ F^2 - D^2)^2}{(16\ F^2 + D^2)^4}.$$

Case C.—Suppose C varies, while D, F, and R remain constant Then—

Total luminous flux from the crater varies as C.

Intensity of illumination at distance R is constant.

Area illuminated at distance R varies as C.

Total utilised flux of light varies as C.

Case D.—Suppose R varies, while D, F, and C remain constant. Then—

Total luminous flux from the crater is constant.

Intensity of illumination at distance R varies as $1/R^2$.

Area illuminated at distance R varies as R^2.

Total utilised flux of light is constant.

Suppose now that D, F, C, and R all vary independently. Then—

Total luminous flux from the crater varies as C.

Intensity of illumination at distance R varies as D^2/R^2.

Area illuminated at distance R varies as

$$F^2\ R^2\ C \frac{(16\ F^2 - D^2)^2}{(16\ F^2 + D^2)^4}.$$

Total utilised flux of light varies as

$$D^2\ F^2\ C \frac{(16\ F^2 - D^2)^2}{(16\ F^2 + D^2)^4},$$

and, of course, width of beam, whether measured vertically or horizontally at distance R varies as

$$F\ R \sqrt{C}\ \frac{16\ F^2 - D^2}{(16\ F^2 + D^2)^2}.$$

For a Diverged Beam.

Where the divergence is horizontal only.

Suppose the beam to be received on a cylindrical surface, the

axis of the cylinder being vertical and at the projector, and the radius of the cylinder being R.

Observe that in all cases the total luminous flux and the total utilised flux of light will be the same as in the corresponding case with the concentrated beam.

Case A.—Suppose D varies, while F, C, R, and θ remain constant.

Then—

Total luminous flux from the crater is constant.

Total utilised flux of light varies as

$$D^2 \frac{(16\,F^2 - D^2)^2}{(16\,F^2 + D^2)^4}.$$

Vertical width of beam at distance R varies as

$$\frac{16\,F^2 - D^2}{(16\,F^2 + D^2)^2}.$$

Horizontal width of beam at distance R is constant.

Area illuminated at distance R varies as

$$\frac{16\,F^2 - D^2}{(16\,F^2 + D^2)^2}.$$

Intensity of illumination at distance R varies as

$$D^2 \frac{16\,F^2 - D^2}{(16\,F^2 + D^2)^2}.$$

Case B.—Suppose F varies, while D, C, R, and θ remain constant.

Then—

Total luminous flux from the crater is constant.

Total utilised flux of light varies as

$$F^2 \frac{(16\,F^2 - D^2)^2}{(16\,F^2 + D^2)^4}.$$

Vertical width of beam at distance R varies as

$$F \frac{16\,F^2 - D^2}{(16\,F^2 + D^2)^2}.$$

Horizontal width of beam at distance R is constant.

Area illuminated at distance R varies as

$$F \frac{16\,F^2 - D^2}{(16\,F^2 + D^2)^2}.$$

Intensity of illumination at distance R varies as

$$F \frac{16\,F^2 - D^2}{(16\,F^2 + D^2)^2}.$$

Case C.—Suppose C varies, while D, F, R, and θ remain constant.

Then—

Total luminous flux from the crater varies as C.

Total utilised flux of light varies as C.

Vertical width of beam at distance R varies as $\sqrt{C}$.

Horizontal width of beam at distance R is constant.

Area illuminated at distance R varies as $\sqrt{C}$.

Intensity of illumination at distance R varies as $\sqrt{C}$.

Case D.—Suppose R varies, while D, F, C, and θ remain constant.

Then—

Total luminous flux from the crater is constant.

Total utilised flux of light is constant.

Vertical width of beam at distance R varies as R.

Horizontal width of beam at distance R varies as R.

Area illuminated at distance R varies as R^2.

Intensity of illumination at distance R varies as $1/R^2$.

Case E.—Suppose θ varies, while D, F, C, and R remain constant.

Then—

Total luminous flux from the crater is constant.

Total utilised flux of light is constant.

Vertical width of beam at distance R is constant.

Horizontal width of beam at distance R varies as θ.

Area illuminated at distance R varies as θ.

Intensity of illumination at distance R varies as $1/\theta$.

Suppose now that D, F, C, R, and θ all vary independently.

Then—

Total luminous flux from the crater varies as C.

Total utilised flux of light varies as

$$D^2 F^2 C \frac{(16 F^2 - D^2)^2}{(16 F^2 + D^2)^4}.$$

Vertical width of beam at distance R varies as

$$F R \sqrt{C} \frac{16 F^2 - D^2}{(16 F^2 + D^2)^2}.$$

Horizontal width of beam at distance R varies as $R\theta$.

Area illuminated at distance R varies as

$$F\ R^2\ \theta \sqrt{C}\ \frac{16\ F^2 - D^2}{(16\ F^2 + D^2)^2}.$$

Intensity of illumination at distance R varies as

$$\frac{D^2\ F\ \sqrt{C}(16\ F^2 - D^2)}{R^2\ \theta (16\ F^2 + D^2)^2}.$$

The diverged beam as already stated being supposed to be received on a cylindrical surface, the axis of the cylinder being vertical and at the projector, and the radius of the cylinder being R.

Remember that these formulæ take no account of the absorption of light by the atmosphere.

CHAPTER XI.

PROJECTORS.

THREE patterns of projector are likely to be met with in the Service, viz. :—

Mark I. Sautter Lemonnier type.
Mark II. Schuckert-Aveling type.
Mark III.

Of these Mark I and Mark II are obsolescent; photographs of these projectors are here reproduced in Figs. 82 to 94. As they are no longer manufactured, a detailed description is not considered necessary. The present Service projector is known as :—

"*Projector*, 90 *cm.* (*Mark III*), with glazed door and reflector frame, but without reflector."

Drawings of this projector have been sealed to govern future manufacture.

MARK I.

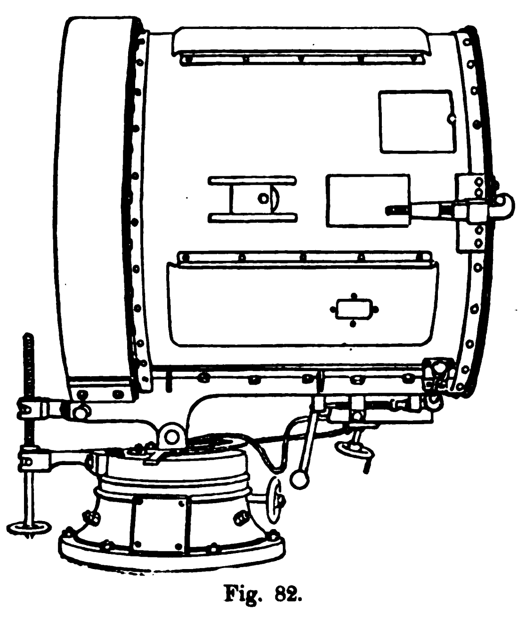


Fig. 82.

MARK I.

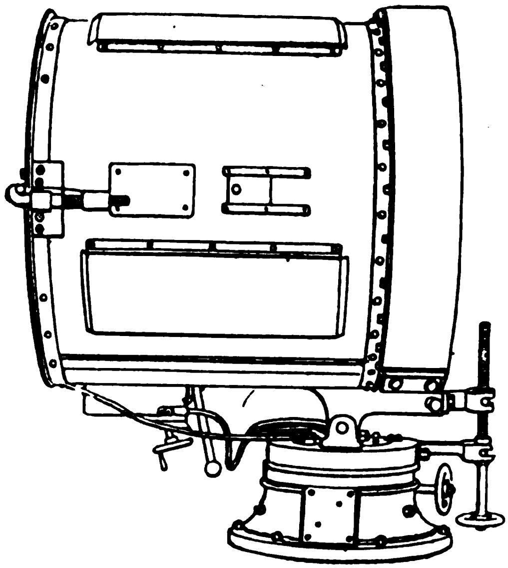


Fig. 83.

MARK I.

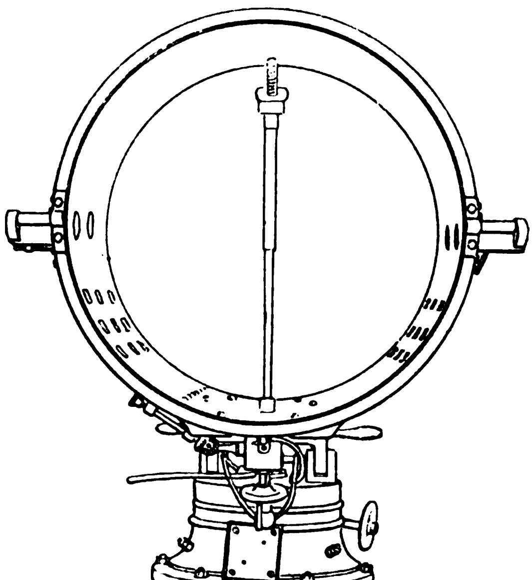


Fig. 84.

MARK I.

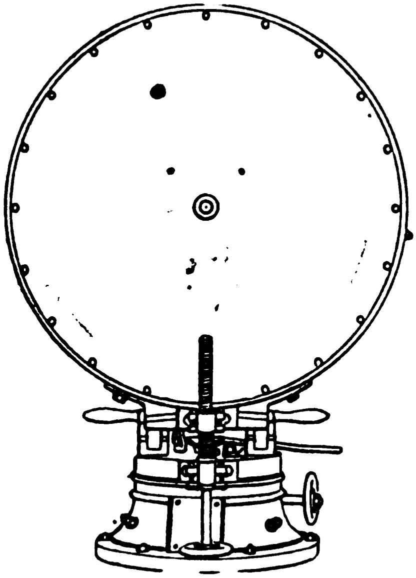


Fig. 85.

MARK II.

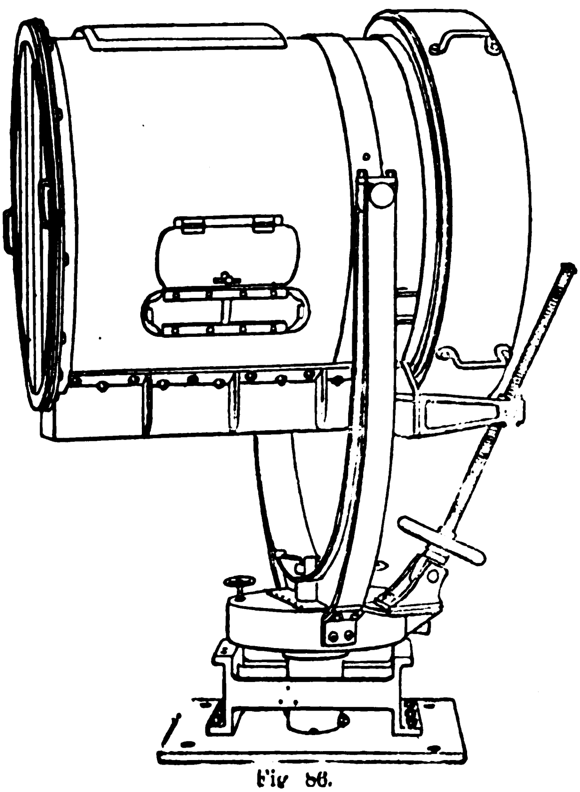


Fig. 86.

MARK II.

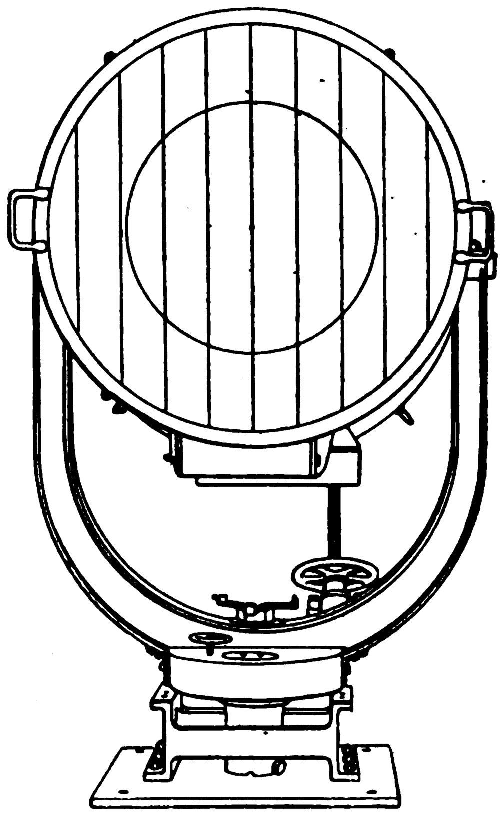


Fig. 87.

MARK II.

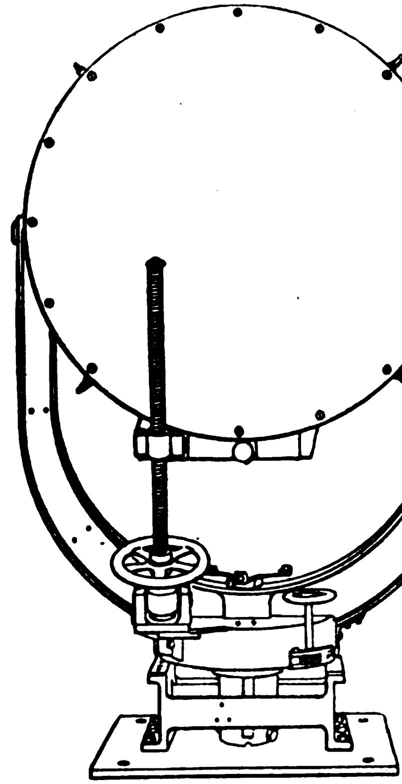


Fig. 88

MARK III.

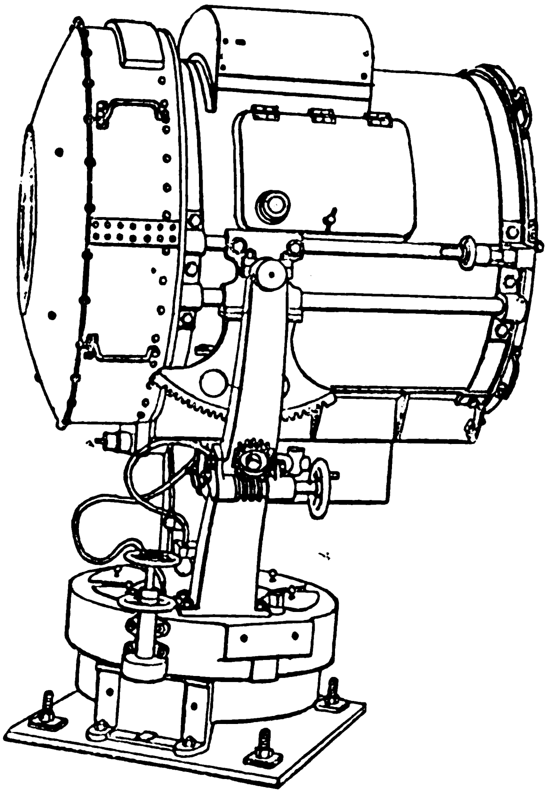


Fig. 89.

Mark III

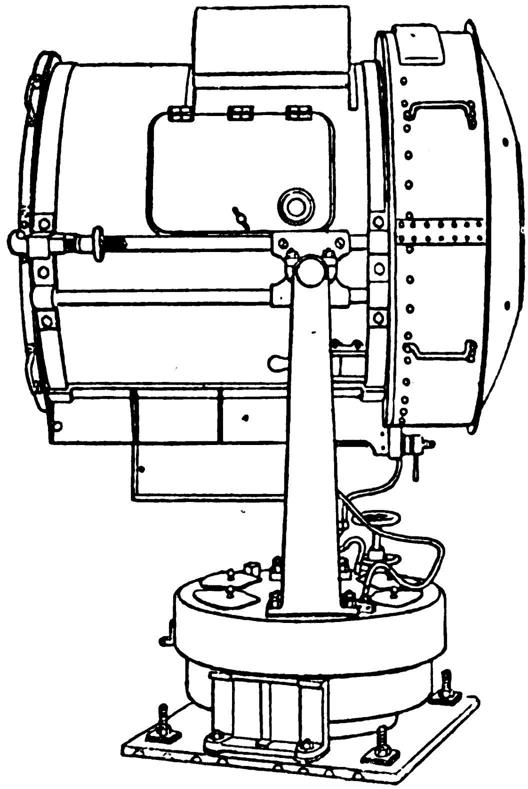


Fig. 90.

Mark III.

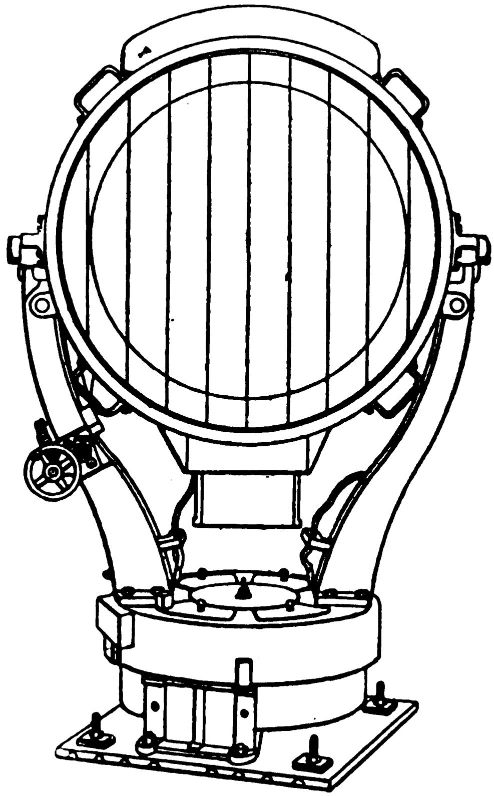


Fig. 91.

MARK III.

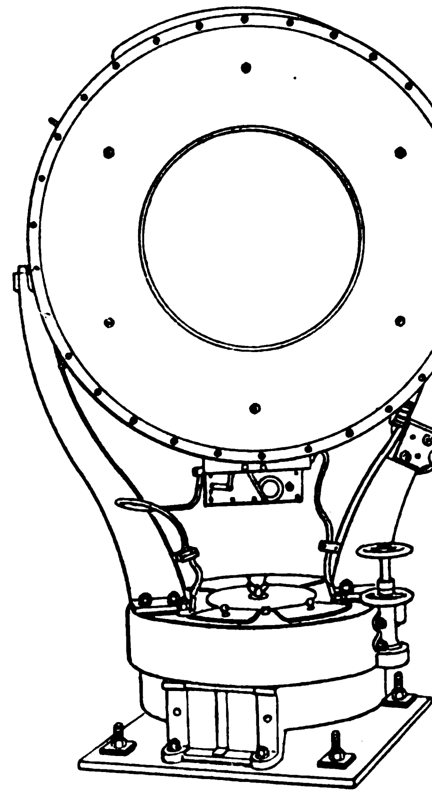


Fig. 92.

The projector comprises the following parts:—

Projector, 90 cm. (Mark III)—

		No. to a Projector.
Body	with arc deflector and six screw studs for securing reflector frame...	1
Bed plate	cast-iron, rectangular	1
Door, glazed	with trunnions	1
Frames, reflector ...	... ...	1
Lugs, terminal—	gunmetal.	
Large	... ...	2
Small	... ...	2
Pedestal, hand elevating only*	turntable, with U arms, and 2 flexible conductors, with lugs	1
Plate, graduated ...	brass, circular; with pillar, wing nut, 2 screw studs, and index. For horizontal training	1
Spanners—		
Box—	T-handled.	
½-inch	for nuts of large terminal lugs	1
¼-inch	for nuts of small terminal lugs	1
Flat, $\frac{3}{16}$-inch	3½ inches long, for pressure screw of main contact bushes	1
Tray, lamp	iron, with 4 handles. For lifting lamp into projector	1

* Motor elevating fitments are only provided in a few special cases.

The body is provided with trunnions mounted on slides by which the balance can be adjusted. Hooks are provided at the front end to carry a glazed door, diverging lens, &c., as may be required. Elevating motion is effected by a toothed quadrant. The reflector frame has dished baffle plates at the back and a row of ventilating holes on top. The terminal lugs fit into sockets in the pedestal. Four contact rings, with rubbing contacts, are provided in the pedestal; two of these are fitted with flexible connections for attachment to a lamp; the other two are of

Mark III.

Side elevation.
Scale $\frac{1}{16}$.

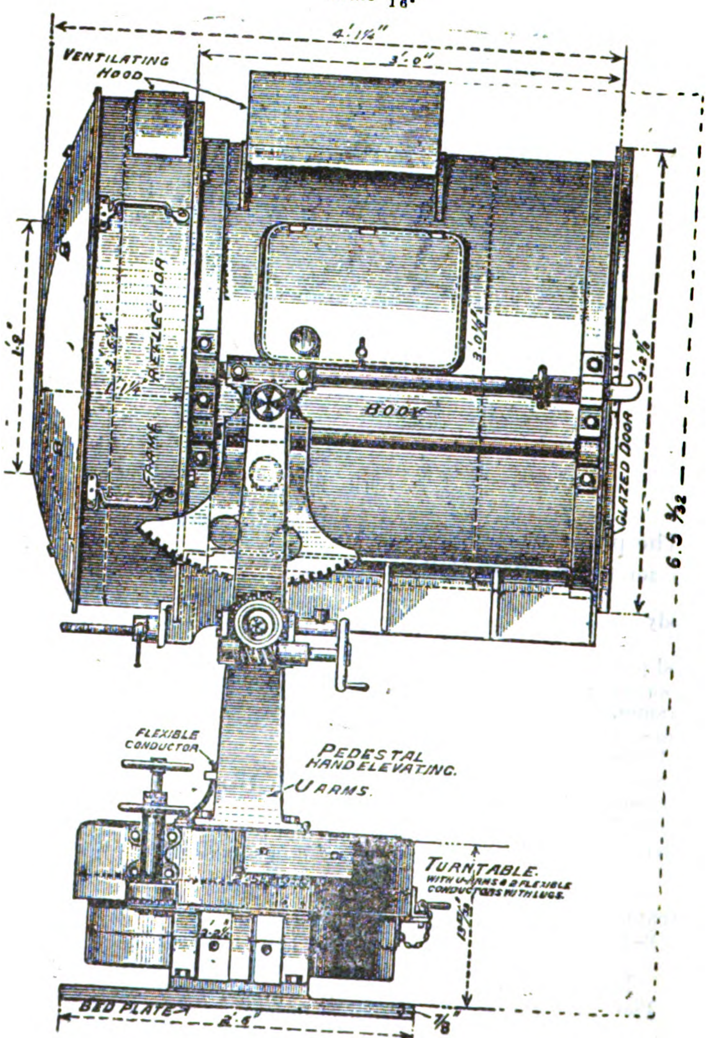


Fig. 93.

smaller dimensions and are intended for use with motors when such are fitted. A well is formed in the centre of the pedestal to receive a directing dial if required. The graduated plate is intended to cover the well when the dial is not fitted.

MARK III.

Sectional elevation (back view)

Scale $\frac{1}{16}$.

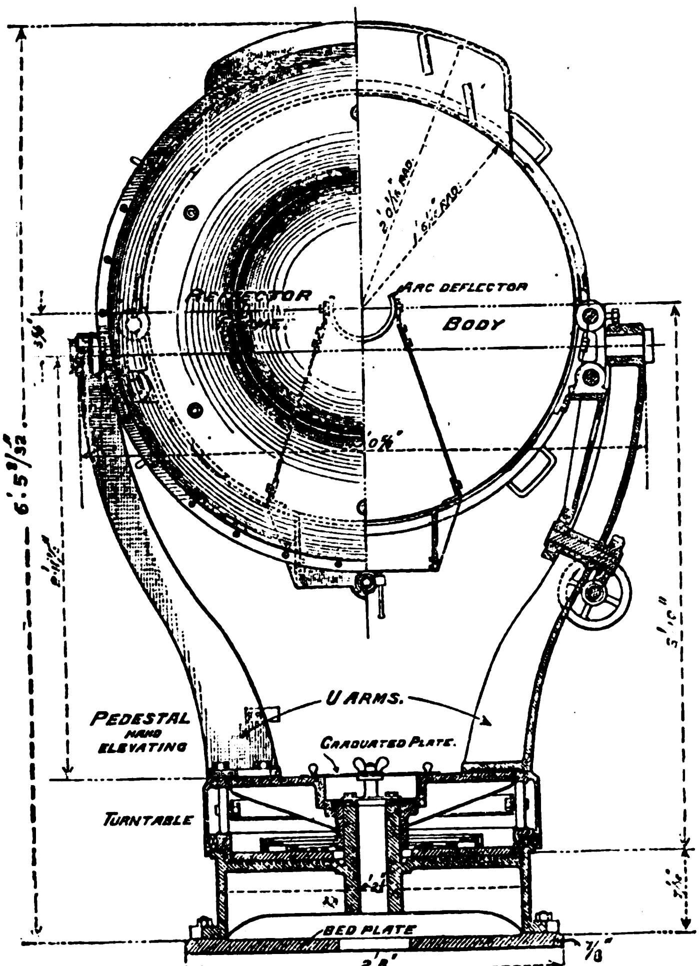


Fig. 94.

Glazed door.

Elevation.

Scale $\frac{1}{16}$.

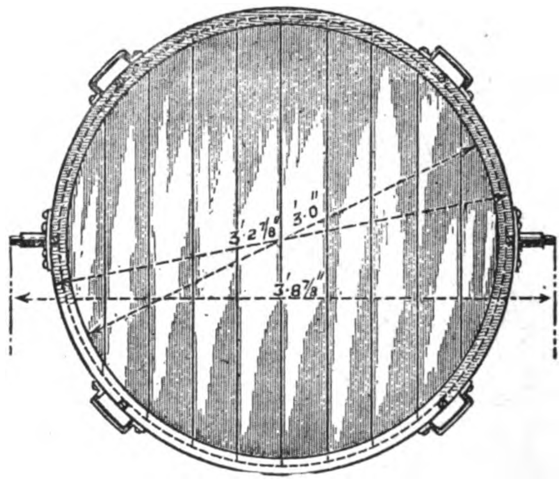
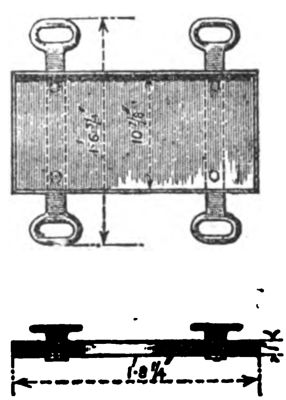


Fig. 95.

Lamp tray.

Plan and elevation.

Scale $\frac{1}{12}$



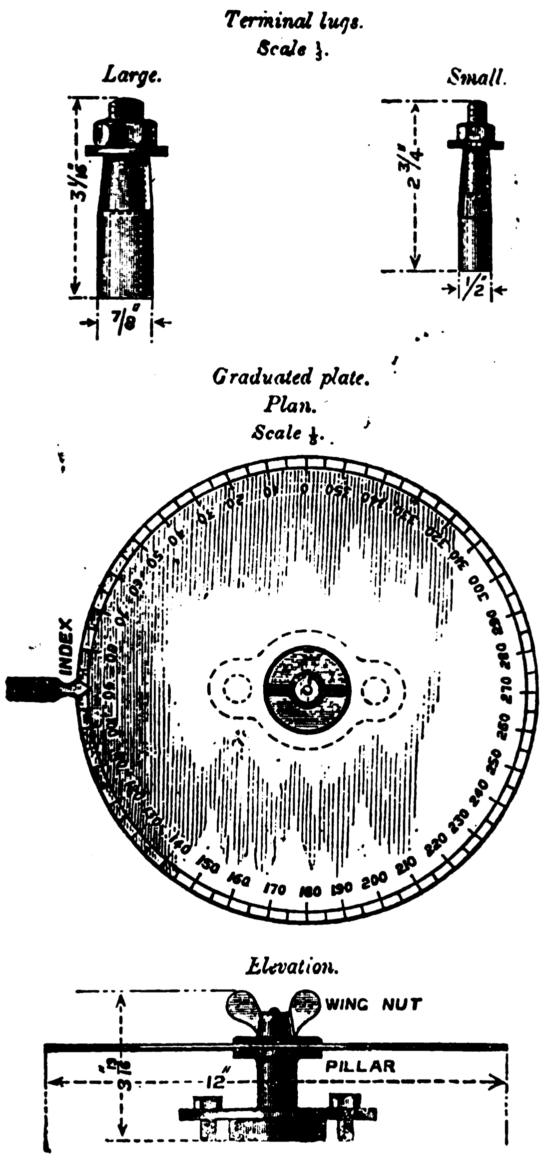


Fig. 96.

Methods of Mounting Reflectors.

Considerable care has been bestowed on the question of mounting reflectors, so that they may not be damaged by the shock of gun fire.

The details of these arrangements are as follows :—

The palladium-faced metallic reflectors are supplied mounted

in their own special mounting rings, which in the case of the most recent supplies are of aluminium: it is not desirable to attempt to dismount these reflectors out of their special mounting rings. The reflector in its special mounting ring can be used in conjunction with Mark III projector, with or without the reflector frame of that projector. It is desirable, as a rule, to use the reflector frame in these cases.

A form of reflector ring made out of channel iron, fitted with 36 sets of opening fingers to clip the reflector, has recently been introduced into the service. It is suitable for mounting any of the following silvered glass reflectors in:—

Paraboloids.
Sphericals.
Parabola-Ellipses 16°, 30°, or 45° divergences.

The diameter of the reflector may be either 894 mm. or 900 mm.—or any intermediate value; moreover, the exact thickness of the glass does not matter, so long as it does not go far outside 10 to 12 mm.

In the case of the parabola-ellipse reflectors of 45° divergence, the two front springs nearest each end of the ellipse section will not assist to hold the reflector in position, but this is immaterial.

A reflector in this mounting ring can be used in conjunction with Mark III projector; using, of course, the reflector frame for its protection.

A form of reflector ring made of angle iron, fitted with 32 sets of opening fingers to clip the reflector, has been largely supplied with silvered glass paraboloids of 894 mm. diameter and 42 cm. focal length. It will be superseded by the ring just described. It can be used in conjunction with either Mark II or Mark III projector; using, of course, the reflector frame for its protection.

Mangin reflectors are mounted with special wooden rings and blocks; they are not provided with an iron reflector ring. When mounted they are protected from injury by the reflector frame of the projector in which they are being used.

The short focal length Mangin reflectors can only be used with Mark III projector. The long focal length Mangin reflectors were originally purchased mounted in Mark I projectors; it is not likely any question of mounting them in other patterns of projector will arise.

A system has been recently introduced of marking reflectors with all important particulars regarding them, to assist in identifying the various types and arranging for their mounting.

As an example, a 90 centimetre diameter, 42 centimetre focal

length, 30° divergence, parabola-ellipse reflector will be found to have the following particulars engraved on its edge, thus:—

90/42/30

TOP | TOP

the lines marking respectively the ends of the parabola and of the ellipse sections.

Care of Reflectors.

The greatest care should be taken of all reflectors.

All chamois leathers, cotton wool, or other material used for cleaning reflectors of any type must be kept scrupulously clean, and every precaution must be taken to avoid scratching the face of a reflector.

In the case of silvered-glass reflectors special cleaning gear is issued.

Palladium-faced reflectors should be lightly cleaned over after each run. For this, cotton wool and a little clean fresh water is all that is generally necessary, but if a more extensive cleansing is required the following procedure should be adopted, and whenever a reflector of this type is splashed with salt water or becomes coated with salt, this should be washed off at the earliest opportunity:—

(i) Flood the surface of the reflector with a 10 per cent. solution of ammonia (pure) and rapidly bathe the surface gently with a tuft or pad of clean cotton wool; then wash well with clean water and dry thoroughly with cotton wool.

(ii) If the reflectors be kept perfectly dry, the cleaning will be found a simple matter when carried out as above.

(iii) Rouge or chamois leather are not to be used.

Mangin reflectors must never be rested on their centres. This part of these reflectors is so thin that it would probably break if the reflector were rested upon it.

All glass reflectors when heated should be shielded as far as possible from draughts, otherwise they may crack.

Special transport cases have been designed for the protection of reflectors when being moved not mounted in projectors.

Patterns of Lamp used with various Projectors.

Mark I projector can only be used with the "lamp, electric, arc, inclined."

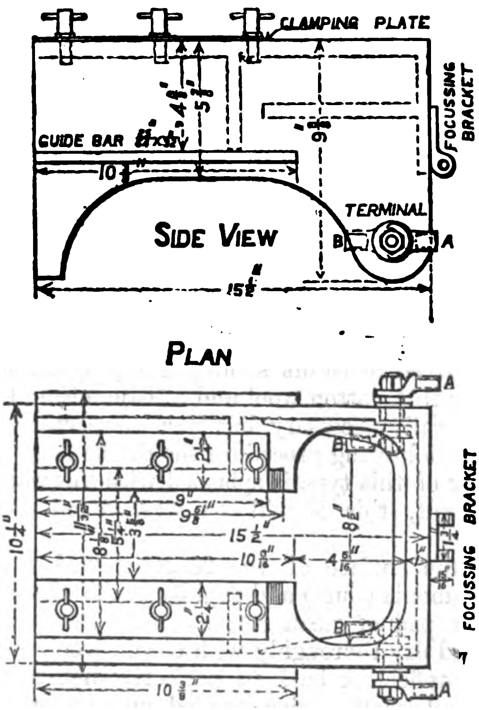
Either Mark II or Mark III projector can, by the use of an "adapter," be used with the "lamp, electric, arc, inclined," *provided the reflector used is one with a long focal length* (*vide* Chapter on Electric Light Projection).

The adapter is made of cast gunmetal, and is of the dimensions shown in Fig. 97; its weight is about 48 lb.

It is provided with guide bars to fit the projector guides, two insulated terminals, fitted on the outside with cable connectors, and on the inside with flexible conductors, for making the necessary connections to the terminals on the inclined lamp.

The lamp is held in position by clamping plates.

The adapter is intended for use in the "projector, 90 cm.," Mark II, or Mark III, with an inclined hand lamp, when the focal length of the reflector is long.



A.—*Connectors for E.L. cable.*
B.—*Terminals for flexible conductors.*

Fig. 97.

Diverging Lenses.

These are supplied for use where required and are held on to the front of the projector by the hooks shown in Fig. 93, the

glazed door being removed. These lenses are made in three patterns of varying divergence, and are known as

Lenses, diverging, 90 cm. diameter—		In gunmetal frame with trunnions
16 degrees... ...	L	With 15 glass prisms, identification letters A to H
30 degrees... ...	L	
45 degrees... ...	L	With 11 glass prisms, identification letters A to F

Each consists of a gunmetal frame 90 cm. in internal diameter, fitted with plano-convex lenticular prisms of crown glass, and provided with four gunmetal handles and two steel trunnions.

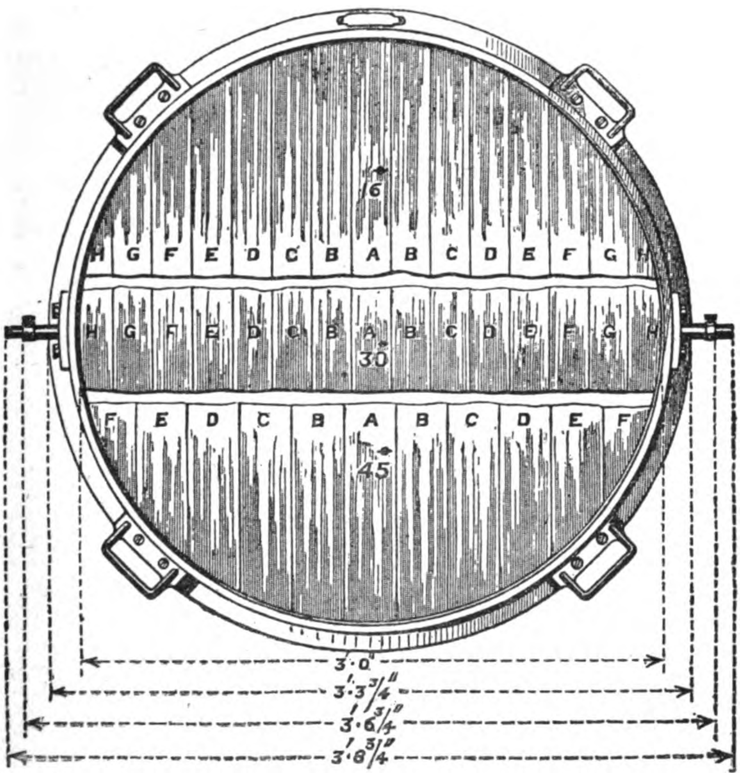


Fig. 98

The frames for the 16° and 30° lenses have each 15 prisms, and the 45° lens has 11 prisms.

The lenses are intended for use with the "projector, 90 cm., Mark III."

When demanding strips of glass for the purpose of repair of either of the above lenses, the identification letter for the strip required (*see* drawing) should be quoted in the demand, as well as the description of lens for which it is required.

Louvred Shutter.

A pattern of louvred shutter has recently been approved. It is capable of being used on the front of projectors, being held in position by its trunnions in the trunnion hooks of the projector. It has vertical louvres.

On a projector furnishing a concentrated beam it can be used for signalling or for obscuring the light; on a projector giving a diverged beam its only use is for obscuring the light.

CHAPTER XII.

ACCESSORIES FOR DEFENCE ELECTRIC LIGHTING.

VOLTMETERS.

OF these, two patterns are likely to be met with, although there is an immense variety of forms. Most of them depend for their action on the magnetic properties of the current. The Service instrument which works on this principle is known as "Voltmeter, electro-magnetic, 80-volt."

Its action is as follows :—

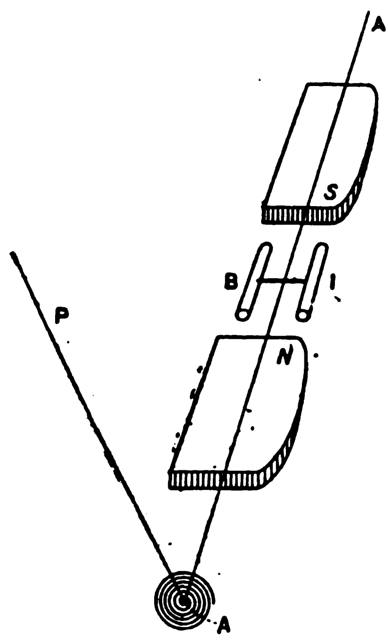


Fig. 99.

N S = soft iron pole pieces.
I = soft iron armature.
B = brass counterpoise.
P = pointer.
A = main arbor.

The two soft iron pole-pieces are fixed on a brass frame into lugs on which is pivoted the arbor A A *above* the pole-pieces. The whole is enclosed in a bobbin not shown in the sketch. The pole-pieces are magnetised by the coil, as shown, and draw down the

armature I between them against the action of the spiral spring, so turning the pointer P over a suitable calibrated scale.

Advantages.—Spring control, therefore readable in any position, very portable, direct reading, and little affected by external fields.

Disadvantage.—Not dead beat.

CARDEW'S VOLTMETER.

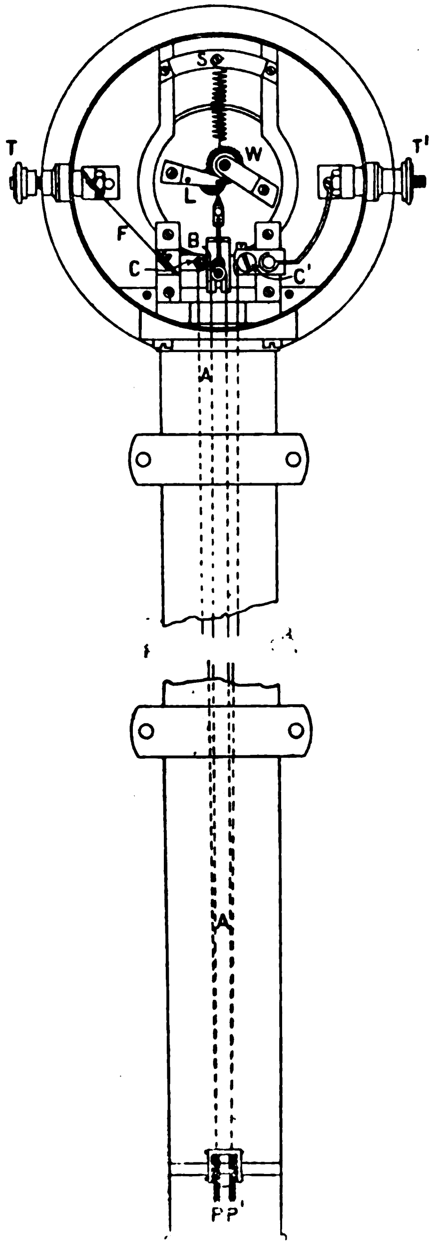


Fig. 100.

The other voltmeter in use in the Service is known as "Voltmeter, hot-wire, 120 volts, Cardew type," and depends on quite a different principle, viz., the expansion of a wire when heated by the passage of a current.

It is made to read either in a vertical or horizontal position, and the wire is either mounted in the tube, as shown, or on a rod which slips inside the tube; in either case the tube or rod is made of brass and iron in the proportion of two lengths of brass to one of iron, as this combination has the same temperature expansion co-efficient as the platinum silver wire used.

The conductor A A (Fig. 100) passes twice up and down the tube; it consists of 12 feet of platinum silver wire, ·0025-inch in diameter. The ends are fixed to the two supports CC′, which are in connection with the terminals T T′. The wire is then passed over the two insulated pulleys P P′, and the centre is passed round the bone block B, which is held in place by the spring S attached to the frame of the instrument. The wire connecting this block to the spring passes round a grooved wheel, the shaft of which also carries a toothed wheel W, geared into a small pinion. On the end of the pinion shaft is fixed a pointer, moving over a dial graduated in volts. The terminal T′ is connected direct to C′, but between T and C is inserted a fine fuze wire, F, ·0014-inch diameter, so that should the current get dangerously large by an accidental increase of volts, the fuze wire may melt, and so save the instrument.

Advantages.—Suitable either for direct or alternate currents, dead beat, fairly even and open scale, unaffected by magnetic fields.

Disadvantage.—Not very portable.

Ammeters.

Three patterns have been used in the Service—

(*a*) The Cunynghame, Woodhouse, and Rawson.

(*b*) Siemens.

(*c*) Schuckert.

Of these *a* is no longer a Service instrument, but may be found on stations; and *b* is obsolescent and is not likely to be met with; *c* is at present the only ammeter in extensive use in the Service for search-lighting.

The ammeter, shown in Figs. 101 and 102, consists of a thick electro-magnet C C, wound with a few turns of stout copper strap, coming to the terminals B B. Into the poles of the magnet are screwed two-round-headed pole-pieces F F, between which is pivoted the soft iron needle N, the axis of which is at an angle of 30° with the line of the poles. The needle is held in this position by a spiral spring, capable of being turned by the milled head T, to which its upper end is fixed. The angle through which the milled head is turned is indicated by a pointer M, moving over a graduated scale. To the needle is attached a light arm A, the end of which passes through a small slit in the dial, its play being limited by a

CUNYNGHAME WOODHOUSE & RAWSON AMMETER.

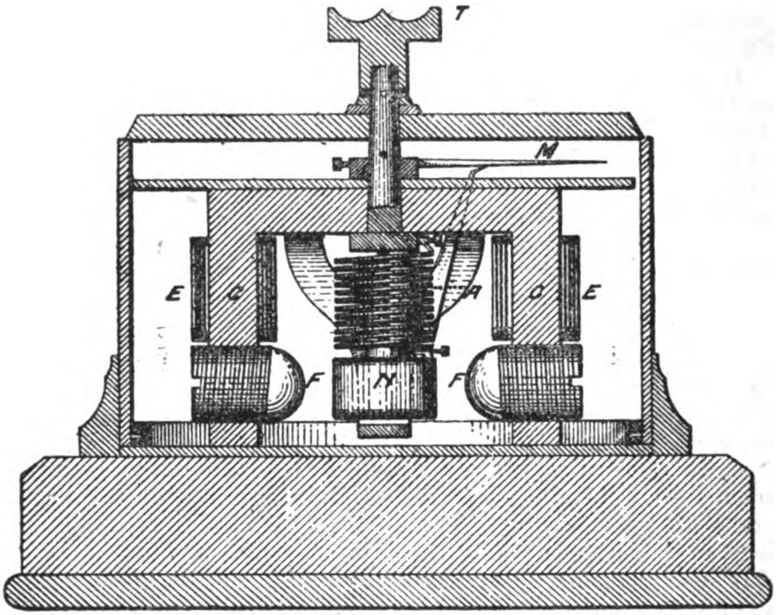


Fig. 101.

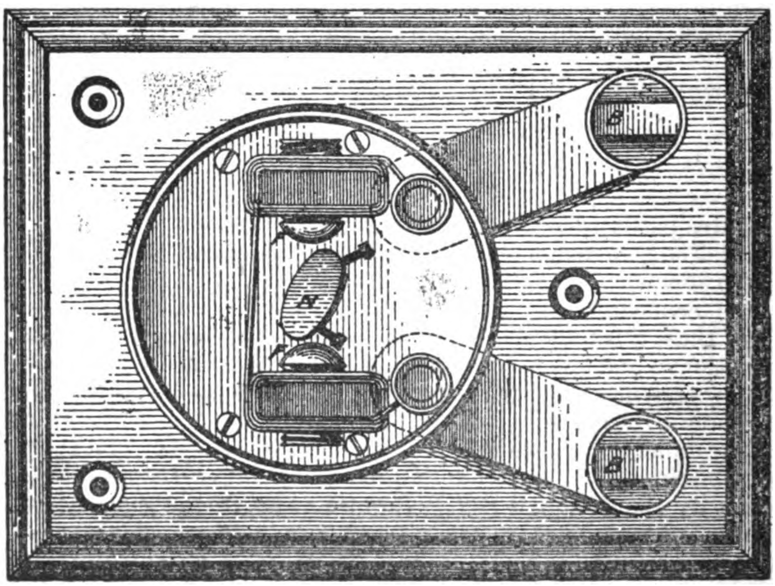


Fig. 102.

pair of stops. When no current is passing through the coils, and the pointer of the milled head is at zero, the arm attached to the needle should rest midway between the stops. When a current is

passed through the coils the electro-magnet is magnetised; the electro-magnet magnetises the needle by induction, and the latter consequently tends to place itself axially with the poles, the arm being dragged over to the left-hand stop. The attractive force can be balanced against the torsion of the spring by turning the milled head till the arm again rests midway between the stops.

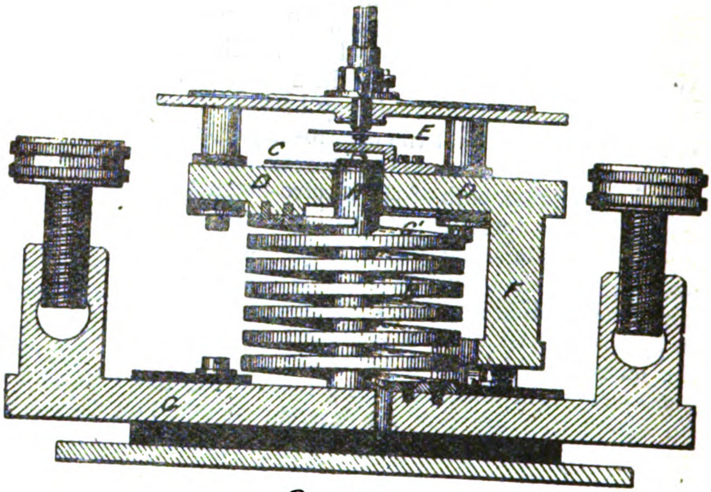
The attractive force of the electro-magnet on the needle varies as the square of the current, as, saturation not being reached, the strength of the poles, both of the electro-magnet and needle, vary as the current. The torsion of the spring varies directly as the angle through which the milled head has been turned; therefore, the current varies as the square root of this angle. The scale is marked in amperes according to this rule. It is found that the readings given by this instrument vary slightly, according to the direction of the current; this is due to traces of permanent magnetism. In consequence, the ammeters are generally marked with an arrow, which shows the direction the current should flow through the instrument.

Siemens Ammeter.

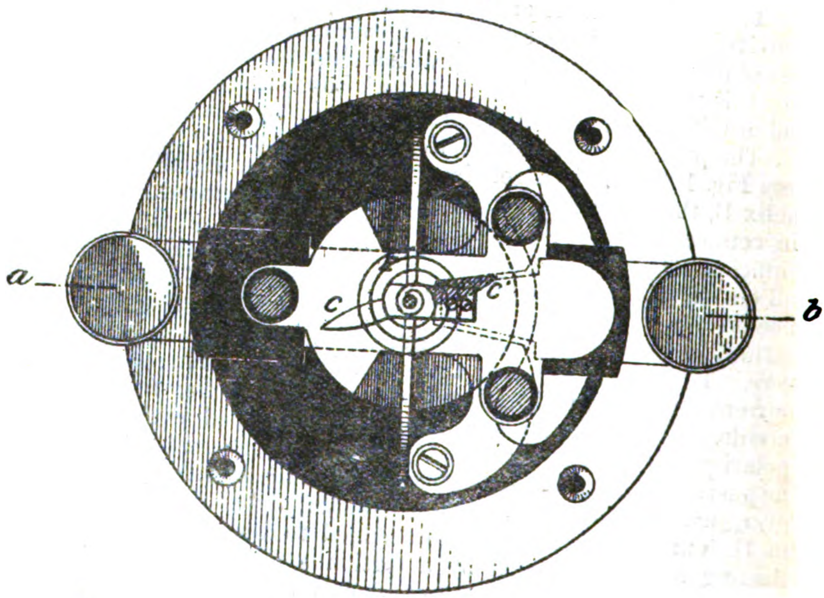
The Siemens ammeter is rather an expensive instrument, and is provided for use as a testing and calibrating instrument for the use of officers in charge of several installations of electric lighting. For this reason it is enclosed in a teak box, padded with sheets of indiarubber, so as to prevent damage from rough handling.

The principle of action of the Siemens ammeter is as follows (see Fig. 103). A is a soft iron core pivoted vertically inside a helix B, through which passes the current to be measured, F being in connection with G. The magnetising power of the helix is sufficient to practically saturate the iron core with magnetism for all currents within the range of the instrument. C is a soft iron needle attached to the top of the iron core, and, therefore, also saturated with magnetism, forming, in fact, the free pole of the core. This moves just over a piece of brass D, through which the current flows, and which, therefore, exerts a deflecting force on the needle. C′ is a similar soft iron needle saturated with the same polarity as C, but projecting at 180° from it, so that no uniform magnetic field has any deflecting force on the system. C′ is, however, just underneath the brass conductor, and the deflecting force of the current on it is therefore added to that on C. This deflecting force is opposed by a torsion spring E, coiled like the hair-spring of a watch, so as to maintain the needle in the same position, and the angle of torsion necessary is indicated by a pointer moving over a scale, the indications being marked directly in amperes, the scale being uniform as soon as saturation is reached. Owing to the two soft iron needles being near together, no ordinary extraneous magnetic field is likely to appreciably affect the instrument, but, of course, it is affected if one pole of a magnet be held very near it. After taking a reading, the ammeter should be short-circuited and the pointer should be turned back to zero, so as not to leave any torsion on the spring.

SIEMENS AMMETER.



SECTION ab.



PLAN. IN SECTION.

Fig. 103.

Schuckert's Ammeter.

The Schuckert ammeter is a much cheaper instrument, and is intended to be fixed permanently in the circuit of each defence electric light as an indicator.

It is a direct-reading instrument which requires no manipulation. It is intended to be fixed against a vertical wall, and is in consequence very convenient for use in an engine room.

SCHUCKERT'S AMMETER.

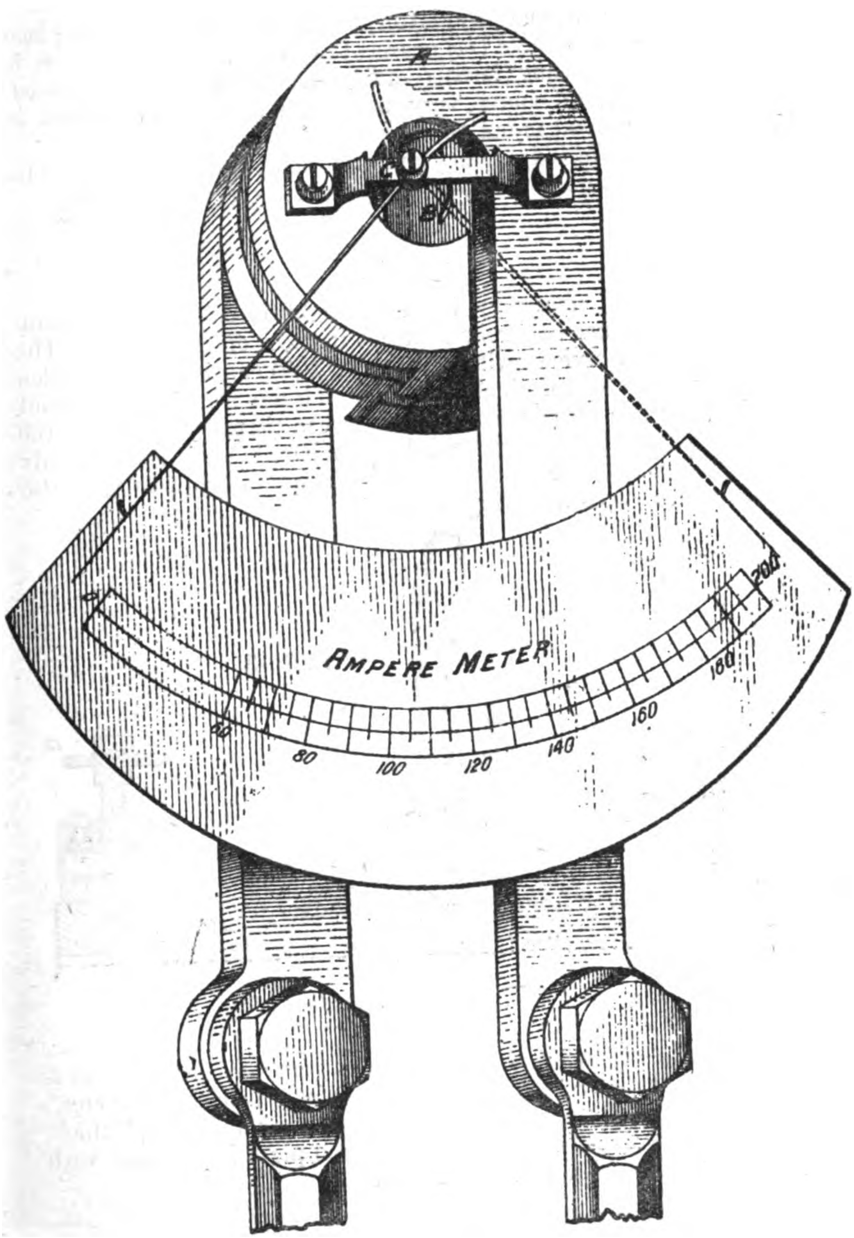


Fig. 104.

Its principle is as follows (see Fig. 104):—

A is a helix of three turns of copper bar; B is a small curved piece of very thin sheet iron, moving at the end of an arm about a pivot C, placed eccentrically as regards the helix. A long pointer moves with the sheet iron over a scale. The arrangement is weighted, so that when no current is passing, the sheet iron is at some distance from the copper helix, although within it; and when a current passes through the latter, the iron moves so as to place itself in a stronger field (*i.e.* nearer the copper conductor); as it does so, the opposing force (gravity) has its moment increased. The forces are, of course, very weak, and the chief drawback is that the instrument is not dead beat.

It is not affected by any uniform field, however strong, but is strongly affected if put near the pole of a powerful magnet.

SWITCHES.

Switches are necessary in search-light circuits, but the main current should not be broken except in cases of emergency. The older form of Service switch (see Fig. 105) consists of a wooden base carrying two terminals *a a*, to which are attached the stout brass straps *b b*. Contact is made between them by means of the shuttle-shaped block *c*, moved by the handle *d*. When firmly pressed down, the block *c* presses the straps outward so as to also make contact with the bridge *e*.

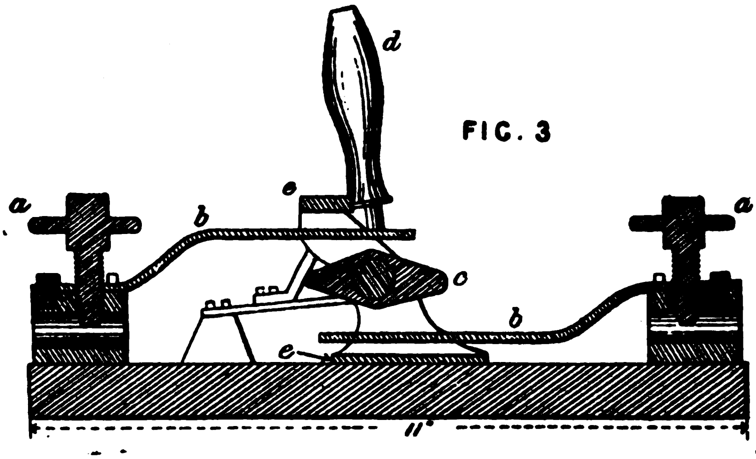


Fig. 105.

This form of switch is not, however, very satisfactory, and is being replaced by "Switch, electric light, single pole, 200 amperes," which consists of an enamelled-slate base 10″ × 7½″ × 1¼″ thick, fitted with two brass contact plates. Each plate is provided with both a terminal and a cable connector.

Scale ¼ full size.

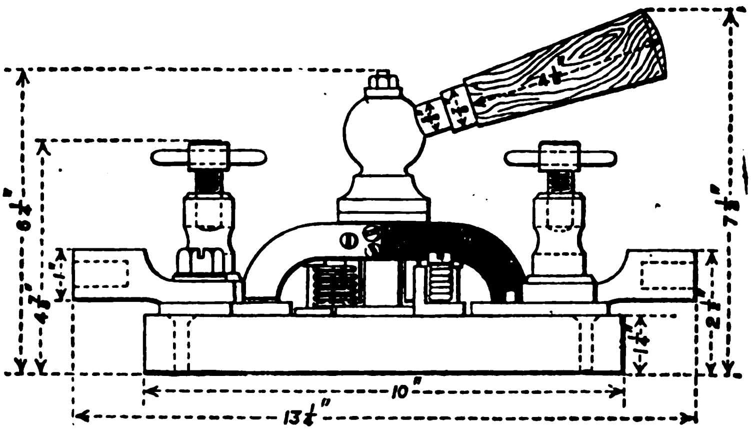


Fig. 106.

The switch bridge is of laminated brass plates, pivoted in the centre and making contact at either end. It is operated by a wooden handle with a loose head, and is fitted with a powerful quick-break action. The terminals and cable lugs are suitable for conductors up to ½-inch diameter.

Scale ¼ full size.

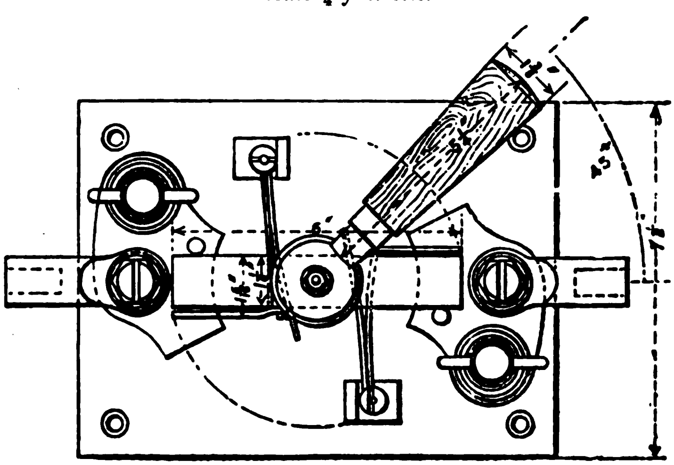


Fig. 107.

Automatic Switches.

For a special purpose in defence electric lighting a pattern of automatic switch has been introduced into the Service, a description of this will be found in Chapter XIII, where the purpose it serves is explained,

Dark Glasses.

These are necessary in order to observe how the carbons are burning. It must be borne in mind that it is most injurious to the eyes to observe the arc at close range, even for a very short time. To do so will probably set up an intensely painful inflammation which will be much felt at night, and prevent the sufferer from sleeping. The form of dark glass now used consists of a wooden frame (Fig. 108) provided with a handle, into the middle of

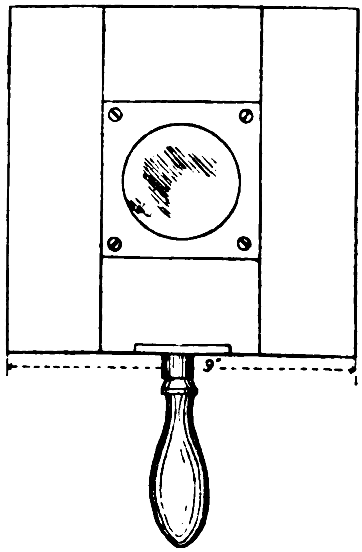


Fig. 108.

which are let two thicknesses of glass, one of "ruby red," and the other of "signal green." These can be easily replaced if broken.

If a dark glass be not available a substitute may be made by smoking a piece of ordinary glass over the flame of a candle.

Pole Indicator, Electrolytic,

or "pole tester," as it is sometimes called, consists of a glass tube filled with a chemical compound into the two ends of which project two white metal electrodes which are provided with terminals outside. In order to determine the polarity of a pair of leads, it is only necessary to attach them to the terminals when, in a short time, the electrode attached to the negative lead will turn a bluish-purple colour. Shaking the instrument will restore it to its normal state.

CHAPTER XIII.

ARRANGEMENT OF DEFENCE ELECTRIC LIGHT CIRCUITS.

In defence electric lighting it is necessary to provide some method of ensuring that the engine shall not race if the arc goes out. When working hand lamps this is a very common occurrence, especially if the operator be unaccustomed to the work.

The method adopted is known as an "automatic switch," by means of which, should the arc from any cause be extinguished, an approximately equal load is automatically thrown on the engine and dynamo, thus preventing the racing that would otherwise occur. Two patterns are likely to be met with, of which diagrams are given in Figs. 109 and 110.

Both depend on the same principle, which consists of the completion of an alternative path for the current by the falling of an armature when the arc goes out. This armature in falling bridges across two mercury cups, but when the arc is alight is held by the action of an electro-magnet clear of the cups.

The older pattern of automatic switch consists of an electro-magnet, M (Fig. 109), wound with a few turns of insulated wire

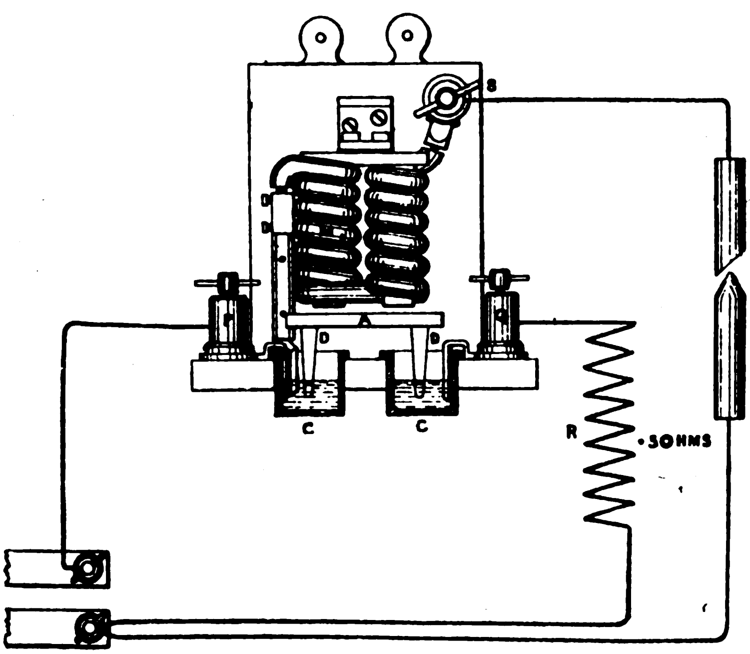


Fig. 109.

thick enough to take the whole current of the dynamo. The ends of the coil go to the terminals S and P. A is the armature which is furnished with two horns D D dipping into two mercury cups C C, one of which is connected to P, and the other to the terminal Q. R is a wire or gauze resistance (*vide* p. 163), of about ·5 ohms resistance, and capable of carrying a current of 150 to 200 amperes. One main lead goes direct from one terminal of the dynamo to the lamp, and to this terminal of the dynamo one end of the resistance R is also attached, the other end being connected to Q. The other main lead is connected to S, and the other pole of the dynamo to P. When the dynamo is started and run at, say 65 or 70 volts, a current of 130 to 140 amperes will evidently be driven through R. When the carbons of the lamp are brought together the current is shunted from R, and a large current passes round the electro-magnet coils. The armature A is attracted, and contact between P and Q is broken. When the light goes out the armature drops, and circuit is again established through R.

This pattern is obsolete but may be met with on stations.

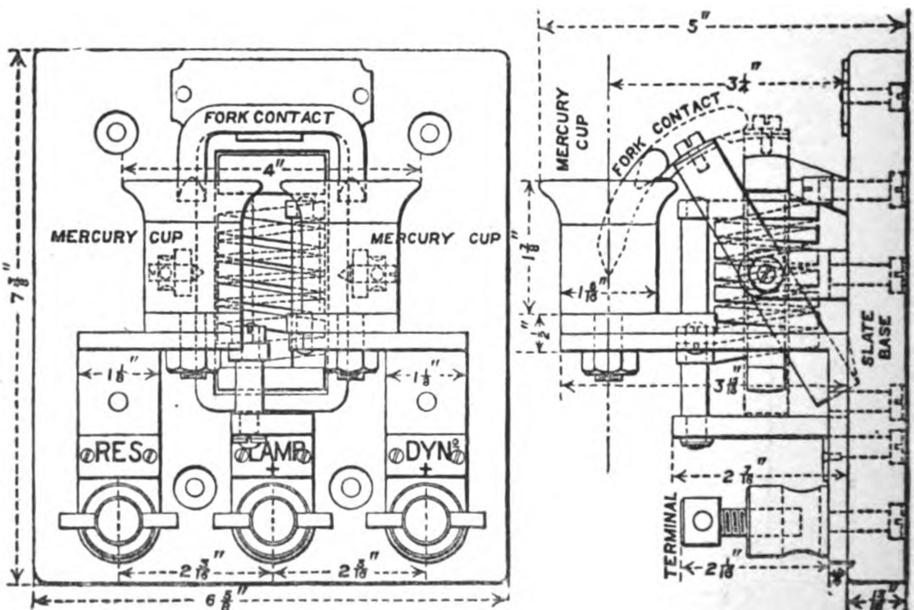
The new pattern is known as "Switch, electric light, automatic (Mark I)."

It consists of a slate slab, 7$\frac{5}{8}$ inches by 6$\frac{5}{8}$ inches by $\frac{13}{16}$ inch, supporting an electro-magnet.

The coil of the electro-magnet is formed of a spiral of bare copper.

The electro-magnet actuates an oblong armature pivoted at its centre to a brass bracket fixed to the slate slab.

The upper end of the armature is fitted with a forked contact



Elevation. *Side view.*

Fig. 11

of copper rod, which rests in two iron mercury cups when the armature is not attracted by the magnet.

The mercury cups are secured to two connecting straps of cast brass provided with terminals. The slab also carries a third terminal, which is connected to one end of the magnet coil, the right-hand terminal being connected to the other end of the coil as well as to the mercury cup.

Three buffer blocks fitted with indiarubber are provided for the armature.

The switch works with a minimum current of 60 amperes, and is intended for use with currents not exceeding 150 amperes in conjunction with "Frames, resistance ·25 ohms," for search-light working with hand regulation.

The approximate weight of the switch is 9 lb. 11 oz.

The resistance employed is fixed and may be about ·5 ohms; *vide* p. 163.

Running one Arc Lamp off a Dynamo.

Whereas the voltage of the latest service generators is constant at 80 volts, the distance between the lamp and dynamo room will vary according to circumstances. It is necessary therefore to introduce some means by which the correct voltage at the lamp can be obtained.

Of course such an end could be obtained by running the dynamo faster or slower, as required, but this method is strongly to be deprecated. In the first place the engine and dynamo have been designed for their proper speed and therefore may be expected to govern and behave better at this speed than at any lower speed, and in the second place, as will be shown by a numerical example, the loads and the fluctuations of load thrown on the machine will be greater by this method of driving than by the proper method, which consists in absorbing the surplus volts by a resistance which is placed in the main circuit and can be adjusted as required. This added resistance in fact forms a very useful and indeed necessary regulator in the circuit. There is a Service store for this purpose, known as a "Frame, resistance, 200 ampere ·25 ohm," but if one of these be not available it is quite possible to extemporise a resistance that will meet requirements.

Let us take an example:—

I. Suppose a compound wound dynamo giving 80 volts at its terminals at all loads, at what distance can we run a 150 ampere hand lamp using C_9 lead?

P.D. of machine = 80.

Now we require at the lamp $40 + \cdot 12\ C$ volts $= 58$ $\therefore$ we may lose in the leads $80 - 58 = 22$ volts.

The resistance of C_9 lead per 100 yards = ·04 ohms (say), $\therefore$ to find length of lead we have

$$22 = 150 \times \cdot 04 \times x.$$

Whence $x = 3\frac{2}{3}$ altogether or each lead may be 183 yards long.

Now this distance might be increased by (i) using leads of lower resistance, (ii) using a light of less amperes, or (iii) over-running the machine. Of these (i) and (ii) are permissible, but (iii) is not.

II. Suppose the distance between lamp and dynamo room to be only 50 yards.

Then the resistance of the leads will be ·04 ohm, and the loss n them = 150 × ·04 = 6 volts, *i.e.* we have 22 − 6 = 16 volts more than we require. Now suppose that the machine be run slower so as to give a P.D. of 64 volts (which will give the 58 required at the lamp).

Now suppose the lamp to go out; at the moment of starting the resistance of the arc is about = ·06 ohm and at this moment the current will be—

$$C = \frac{64}{\cdot 04 + \cdot 06} = 640 \text{ amperes.}$$

Instead of running the machine slower, let us absorb the surplus volts by an added resistance.

$$R \text{ required} = \frac{16}{150} = 0{\cdot}1066 \text{ or say } \cdot 11.$$

Then as before at moment of restarting lamp

$$C = \frac{80}{\cdot 04 + \cdot 11 + \cdot 06} = 381 \text{ amperes,}$$

i.e. a considerably lower maximum current than before, and therefore less strain on the generator and gear generally. The added resistance moreover acts as a buffer between the light and the generator and tends to steady the light and produce better burning.

The "Frame, resistance, 200 amperes, ·25 ohm," consists of an iron frame, the ends being formed of cast-iron, the sides of 1-inch gas piping.

The resistance coils are of galvanised-iron wire, ·171 inch in diameter (No. 7½, S.W.G.), formed into helices and arranged four in parallel. The helices are supported on porcelain insulators at the ends of the frame, intermediate connections being made by brass connecting bars.

The coils at the front and back of the frame are prevented from coming in contact with each other by porcelain insulators fixed to iron crossbars.

To the centre of the frame is fixed an 11-point switch, mounted on a cast-iron frame, the various points of the switch being connected to the resistance coils by bare copper wire, ·232 inch in diameter (No. 4, S.W.G.).

The total resistance of the frame when a current of 150 amperes is passing is equal to ·25 ohm, divided by means of the switch into 10 steps of ·025 ohm each.

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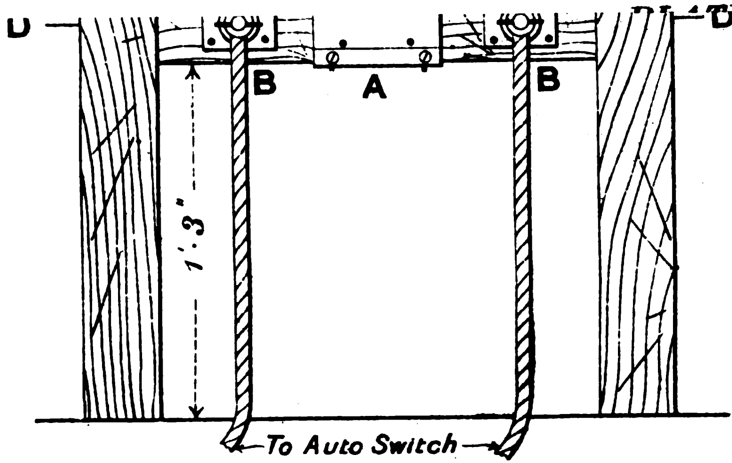
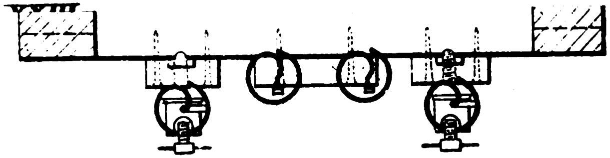


ELEVATION



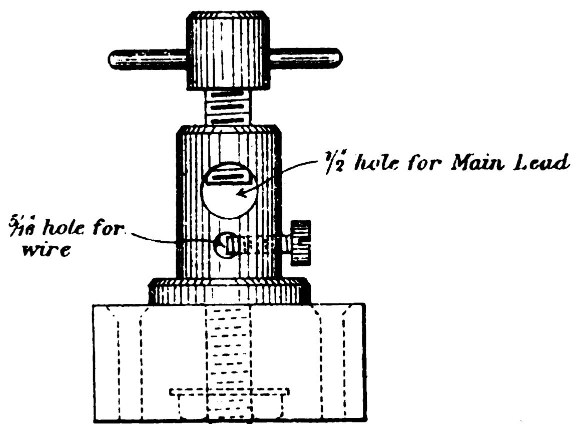
SECTION ON LINE D.D.

FOR DETAILS OF A.A.A. AND B.B. SEE PLATE 2.

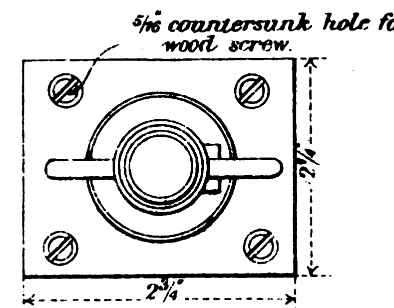
E. Weller & Grahams. Ltd Litho. London

733. 6. 1900

To face page 163.



PLAN



ELEVATION

BRASS TERMINAL ON SLATE BASE B.B.

E. Weller & Grahams. L.td Litho. London.

133. 6. 1900

The frame is also intended for use in connection with an automatic switch, already described, to form an automatic shunt for search-light working.

For this purpose two frames are required, connected in series, or an improvised resistance, as described below, may be used instead.

The Service frame can also be used either separately or in conjunction with other resistances for electric lighting purposes generally: its weight is 228 lb., and its dimensions are—

	Ft.	in.
Height	8	0
Width	2	$0\frac{1}{2}$
Depth, front to back	1	$1\frac{3}{8}$

(i) Plates XXIII and XXIV illustrate the improvised resistance referred to above.

(ii) The resistance is about ·7 ohm, so that, when first switched on, the current (with the dynamo running at 80 volts) is about 114 amperes, which gradually falls to 70 amperes as the temperature of the wire helices rises. The heat of the wire is then such that it can be touched with the hand without hurt, and does not increase.

(iii) Frames of this type may be constructed locally by R.E. labour if a sufficient number of frames of the Service pattern are not available.

To run two Arcs in Parallel off one Generator.

There is no difficulty in running two arcs in parallel off one machine provided the circuits be properly arranged. The point to bear in mind is that the two circuits *must be separate and independent throughout their whole length, i.e.* from dynamo to lamp. A numerical example will clearly indicate the reason of this.

As before, imagine a generator of terminal P.D. = 80 volts, and let it be required to run two 100 ampere lamps (X and Y) in parallel off it, with C_7 lead at a distance of 100 yards..

I. Suppose the lamps in simple divided circuit across the mains.

As before P.D. = 80 volts.

Required at lamps = 52 volts (40 + ·12 × 100).

∴ Loss in leads and resistance = 28 volts.

Of this the leads absorb 200 × ·04 = 8 volts, and therefore the added resistance must be ·1 ohm.

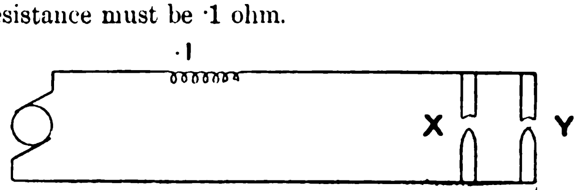


Fig. 111.

Now since each lamp has 52 volts on its terminals and 100 amperes through it, by Ohm's law it must have an equivalent resistance = ·52 ohm, when alight.

Let us suppose the carbons in lamp X to touch, then the current will be:—

$$C = \frac{80}{\cdot04 + \cdot1 + \dfrac{\cdot52 \times \cdot06}{\cdot52 + \cdot06}} = 400, \text{ say}$$

and with this current the loss from machine to lamps will be = CR = 400 × ·14 = 56 volts, whence the P.D. at the lamps falls to 24 and lamp Y will immediately go out.

But with circuits arranged as follows:—

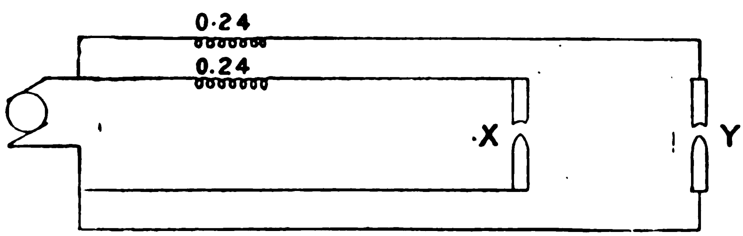


Fig. 112.

Consider the circuit of one lamp:

As before P.D. of machine = 80 volts.
Loss in leads = 100 × ·04 = 4

76
Required at lamp 52 ... 52

∴ We must lose in resistance 24 volts,
or resistance must be ·24 ohms in each case.

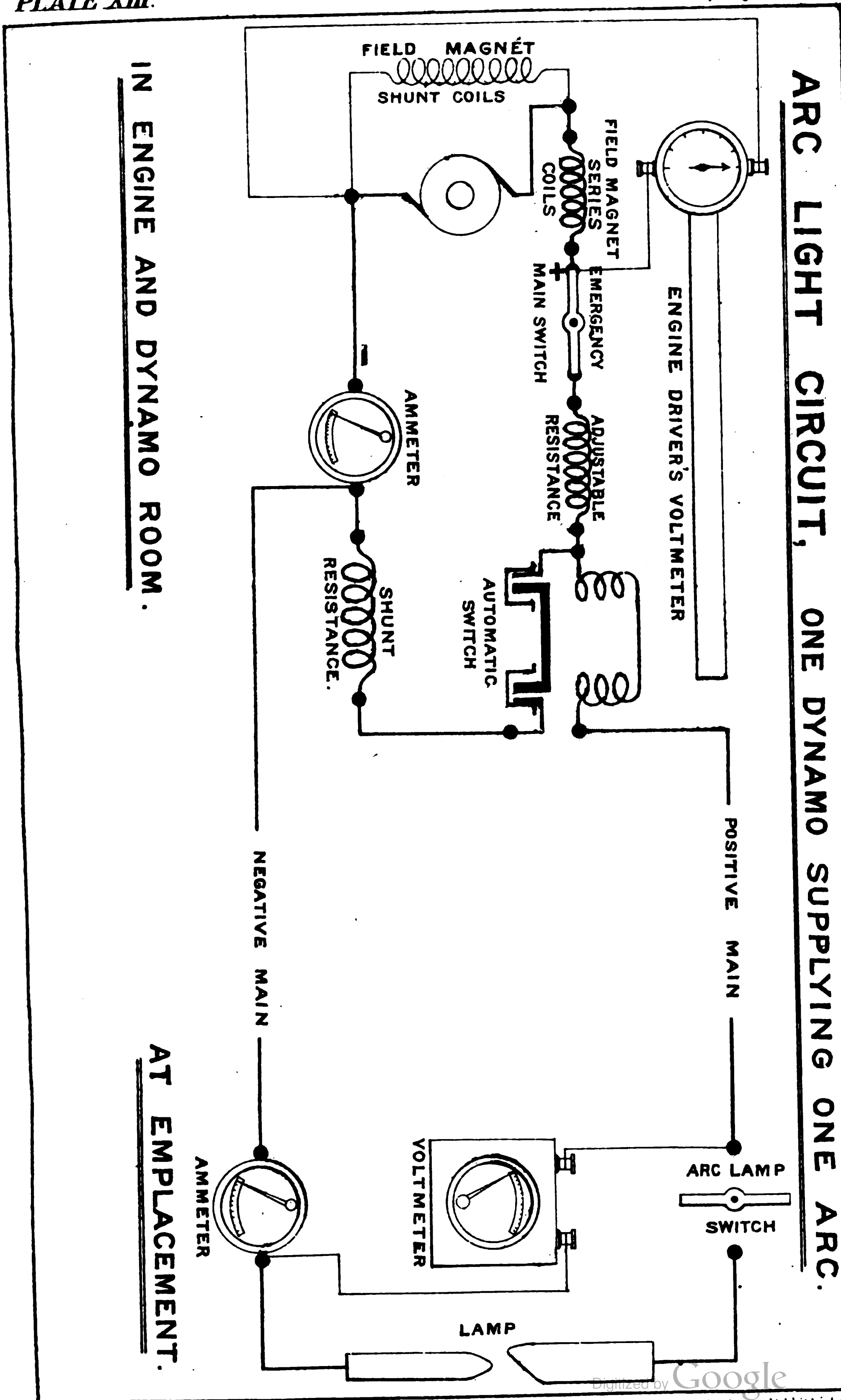
Now suppose the carbons in X to touch, then the current through this branch will be

$$\frac{80}{\cdot24 + \cdot04 + \cdot06} = 235 \text{ amperes,}$$

and if the dynamo be capable of giving up to say 350 amperes this would make no difference to lamp Y since the dynamo is compounded with a level characteristic. With an ordinary Service machine, however, giving 200 amperes at 80 volts, such an increase of current would cause some loss of volts in the machine itself, but not sufficiently so to affect the burning of lamp Y, and thus independence of burning is obtained by this method.

Two lamps *may* be run as above with an automatic switch in *one* circuit *only* should two not be available, the other circuit being unprotected by a switch. Of course a preferable and correct Service arrangement is to have two switches one in each circuit.

Diagrams are given (*Plates* XIII and XIV) of defence electric



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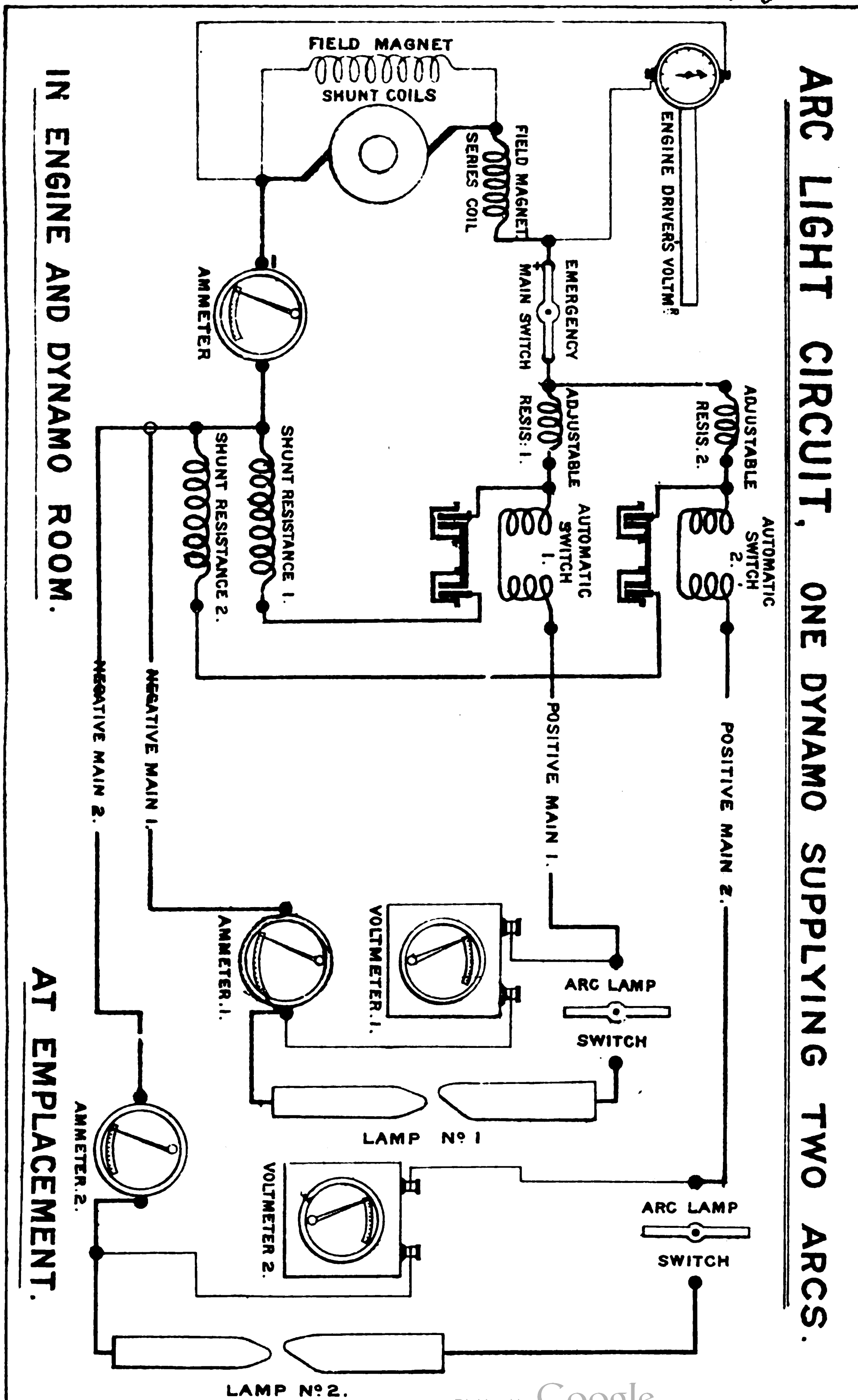

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light circuits for one and two arcs respectively. The usual arrangements of instruments, as there shown, is to have the running resistance, automatic switch and lamp switch in the positive main, and the ammeter in the negative main; the volt-meter must be attached so as to enable the volts at the lamp emplacement to be read before the lamp switch is closed.

It must be noted that, should one bare lead be used or should one lead be very leaky, this must be used as the positive main, for the reason that with many inclined lamps, the positive is but poorly insulated from the body of the projector; in the old Mark I lamp, indeed, the positive is absolutely connected to the body of the lamp.

CHAPTER XIV.

LEADS AND JOINTING.

In the annexed table of leads used in the Service, it will be noticed that the carrying capacities of the various wires do not correspond with the latest recommendations by the Institution of Electrical Engineers. The capacities here given are those given in the Vocabulary of Stores which are based on rules which have been worked to for Service requirements for some years and have been found to answer well. They may be safely adhered to for search light working, but for incandescent wiring the latest rules of the Institution of Electrical Engineers should be followed. They will be found in Chapter XVII.

In running any of the wires outdoors, they must (with the exception of K_5) be laid in pipes. Pipes must be laid *straight* (both horizontally and vertically), and joint boxes must be provided at every angle and at every 150 feet in a straight run. A stout wire must be laid in the pipes during the construction of the pipe line for the purpose of drawing in the wires.

Wires should never be laid in cement, which rots the insulation.

TABLE of Covered Wires used in Electric Lighting.

Vocabulary Name.	Number of Strands and Diameter of Each.	Covering.	Outside Diameter.	Weight per 1,000 Yards.	Resistance per 1,000 Yards.	Uses and Remarks.
			Inch.	Lbs.	Ohms.	
C_5	3 { 22 S.W.G. ·028″	Vulcanised rubber and primed tape...	·175	71	13·85	Electric lighting up to 6 amperes
C_7	37 { 15 S.W.G. ·072″	Vulcanised rubber, primed braided hemp tape, and coated ozokerit compound	·876	2,500	·163	E.L. up to 250 amperes. Resistance for S.L. calculations generally taken as ·02 per 100 yards
C_9	19 { 15 S.W.G. ·072″	Same as C_7	·66	1,359	·32	E.L. up to 150 amperes. Resistance for S.L. ·04 per 100 yards
C_{10}	7 { 15 S.W.G. ·072″	Same as C_7	·457	562·5	·876	E.L. up to 50 amperes
C_{11}	70 { 35 S.W.G. ·0084″	Served cotton, lapped pure rubber tape, sewed two layers cotton, and braided cotton, black and yellow	·176	60	6·28	Single } For flexible connections to incandescent lamps
C_{12}	70 { 35 S.W.G. ·0084″ but 2 cores		·176 per core	130	6·28 per core	Twin } For flexible connections to incandescent lamps
C_{13}	1,064 { 28 S.W.G. ·0148″	Served two layers cotton, lapped two layers pure rubber tape, lapped felt tape, braided hemp, and coated ozokerit compound ...	·82	2,294	·134	For flexible connections up to 300 amperes
C_{14}	535 { 32 S.W.G. ·0108″		·55	1,070	·285	For flexible connections up to 200 amperes

TABLE of Covered Wires used in Electric Lighting—continued.

Vocabulary Name.	Number of Strands and Diameter of Each.	Covering.	Outside Diameter.	Weight per 1,000 Yards.	Resistance per 1,000 Yards.	Uses and Remarks.
			Inches.	Lbs.	Ohms.	
C_{16}	38 S.W.G. ·006″	Served cotton, insulated vulcanised rubber and braided cotton, two wires laid up together ...	...	...	...	Twin for flexible connections up to 6 amperes
C_{17}	1 16 S.W.G. ·064″	Vulcanised rubber, primed tape, braided cotton, and coated ozokerit compound	...	37	7·758	Currents up to 10 amperes
C_{18}	7 18 S.W.G. ·048″	Vulcanised rubber, primed tape, braided tarred flax, and coated ozokerit compound	...	149	1·931	Currents up to 27 amperes
K_4	37 15 S.W.G. ·072″	Vulcanised rubber, primed tape and ozokerit compound, lead tube, braided and coated ozokerit, unarmoured	1·015	4,900	·163	For drawing into pipes for currents up to 250 amperes
K_5	37 15 S.W.G. ·072″	Vulcanised rubber, primed tape, ozokerit compound, lead tube, ozokerit compound, lapped steel tape, braided and coated preservative compound	1·294	7,400	·163	For use underground for currents up to 250 amperes

Jointing the Conductors of C_{10} or any 7-Stranded Leads.

Scarfed Joint.

1. Bare the conductor for a distance of 2 inches.

2. Unlay, clean, and relay the ends, then sweat them up solid for a distance of 1 inch from their tips. Resin only must be used as a flux.

3. Scarf the ends with a suitable file, the length of the face of the scarf being 1 inch.

4. Adjust the jointers vice and grip the conductors close to the insulation, the scarfed faces being opposed to each other in a vertical plane.

5. Secure one end of a piece of binding wire (Z 28, *i.e.* No. 26 S.W.G. copper, tinned,) to one clamping screw of the vice, and take a few open turns tightly round the joint from one jaw to the other to keep the scarfs in position for soldering. With very little solder on the bolt, sweat the scarfed faces together. Remove the binding wire and smooth the joint with a file, taking great care not to cut into the wires on either side.

6. Take a piece of Z. 28 binding wire, 8 feet long bent in four, and place the double bight on the left hand clamping screw of the vice. Cut through the single bight so as to have four free ends. This will prevent the wires from over-riding during the binding.

With the four wires side by side, bind over the wires from a point ¼″ to the left side of the scarf, to a corresponding point on the right side, pressing the turns close up together with the thumb nail and pulling them tight. Secure the free ends round the right hand clamping screw of the vice.

7. Sweat through the joint and binding wire, cut away the loose ends, and smooth the joint over as before.

Twist Joint.

The twist joint may be used when time is a consideration or when the leads are likely to be subjected to any appreciable tensile strain.

It is made as follows :—

1. Bare the conductors for a distance of 6″.
2. Unlay and if necessary clean the wires separately.
3. Cut away 3½″ of the centre wires of each conductor.
4. Unlay the six outer wires to the short ends of the centre ones.
5. Marry the two splayed ends and twist those of each conductor over, and in the opposite direction to the lay of the standing part of the other, taking care to prevent the wires over-riding.
6. Tighten up with the pliers and sweat through the centre of the joint with solder.

JOINTING THE CONDUCTORS OF C_9 AND C_7 LEADS.

Note.—A twist joint is never made with these conductors; the joint must be scarfed.

1. Bare the conductors for a distance of 4″.

2. Unlay and bend back the outer layer of wires (12 wires in C_9 and 18 wires in C_7), the remaining 7 in C_9 and 19 in C_7 form the core, and are referred to as such below.

3. Cut 1 inch of both cores clean away and then treat them as in para. 2 jointing C_{10}.

4. As in para. 3 jointing C_{10} lead.

5. Improvise two rigid supports, such as two stiff pieces of wood 9″ × 3″ × 1½″, grooved across their flats about 1″ from the end to form a bed for the leads. Secure them in a vertical position against the edge of a bench or plank having a clearance between them of 6″. Insert a small screw in each support about 3″ from the top and close to the inner edge on the grooved side for securing the binding wire referred to in para. 7.

6. Firmly secure the ends of the leads in the grooves with spun yarn or better still No. 16 G.I. binding wire having the scarfed faces opposed to each other and in a vertical plane.

7. As in para. 5 jointing C_{10} leads, the binding wire being secured round the heads of the small screws.

8 and 9. As in paras. 6 and 7 jointing C_{10} leads.

10. Clean the wires forming the outer layer and lay up those on the left hand side into their normal positions. Then lay up those on the right hand side until they reach the ends of those on the left.

11. Marry the outer layers as follows:—

(*a*) Take any two* consecutive wires on the right hand side and the two corresponding wires on the left. Unlay the latter and lay the former in their place cutting off the left hand wires to butt against the ends of those of the right.

(*b*) Take the next pair of wires on the right and cut them off short to butt against the ends of the corresponding left hand pair already laid up.

(*c*) Take the third pair of wires and treat them as the first pair, the fourth pair being treated as the second and so on with the fifth and sixth pairs.

12. Serve over the two sets of butts with No. 26 binding wire, in the manner previously explained, each serving to extend ½″ on either side of the butts.

13. Sweat the two servings to the outer layer of the conducting wires and smooth the whole over with a suitable file.

Note.—As regards the K cables, the electrical joint is made as detailed above. These cables should be demanded of the exact length required so as not to necessitate jointing; should the necessity arise, a special junction box must be devised.

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* In jointing C_7 leads three wires should be dealt with each time instead of two.

Insulating the Joints.

1. Bare the insulation on each side of the joint, by removing the braided hemp and tape coating for a distance of $2\frac{1}{2}''$. Great care must be taken not to cut the rubber.

2. Scrape the rubber lightly to remove all threads and dirt, then trim the ends to a taper $1\frac{1}{4}''$ long the pure rubber if possible being just exposed at the bottom of the taper. The parts thus trimmed must be kept perfectly clean, and not exposed to the air for a longer period than is necessary. If by any means they become in the least dirty, they must be wiped over with a piece of clean rag, free from fluff, damped with benzole.

3. Lap the conductor with one layer of pure rubber tape $\frac{5}{8}''$ wide,* applied half lap as tightly as possible extending from the bottom of one taper to the other, if the pure rubber be not available Service $\frac{1}{2}''$ tape† may be used.

4. Apply a little vulcanising solution to the bevelled surfaces of the rubber with a knife, Then apply the compound rubber strips each $\frac{3}{4}''$ wide (Silvertown No. 6810, vocabularised as tape I.R. vulcanising) half lap, forming a uniform covering over the joint from the top of one taper to the top of the other, slightly exceeding the diameter of the original insulation. The rubber should be warmed by the flame of a spirit lamp before using, being cut off in lengths not exceeding 6″ at a time. If tape shows signs of brittleness when being applied it should be warmed again.

5. Apply a layer of (Silvertown No. 731 vocabularised as tape, single primed $\frac{7}{8}''$) single proofed tape $\frac{7}{8}''$ wide single lap, extending from outer braiding to outer braiding, and secure the ends with I.R. solution.

Vulcanising.

1. Cover the joint with two half lap layers of double proofed tape $1\frac{5}{8}''$ wide and bind as tightly as possible, extending over the braiding sufficiently to clear the grips of the cure. The tape will thus serve as a mould and keep the joint from actual contact with the molten sulphur.

2. Place the joint in the cure, adjust the asbestos washer and pack the ends before bolting down, to prevent any leakage of the sulphur. Light the spirit lamps and place them in position to warm the cure.

3. Sufficient sulphur to fill the cure should be melted in a suitable pot during the preparation of the joint.

The molten sulphur should be raised to a temperature of 320° F., and then poured into the cure through the filling hole with a small ladle and funnel. The thermometer supplied for the purpose should then be placed in the hole to enable the temperature of the sulphur to be noted. The bulb must not be allowed to touch the metal of the cure.

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* Silvertown No. 61, vocabularised under "Materials for Jointing and Vulcanising Electric Cables" as "Tape I.R. pure."

† Vocabularised as "Tape I.R."

The temperature must be kept as constant as possible between 290° and 300° F. by means of the spirit lamps, the flames of which must be adjusted accordingly.

4. After the joints have been cured for 20 minutes, remove the lamps and run the sulphur out of the cure. Unbolt the cover, take out the joint, and remove the wrappings of double proofed tape. Should a test of the degree of vulcanisation be required, the single proofed tape must be removed and (when the joint is cool) the thumb nail applied to the rubber, if the mark of the nail remains, or if the rubber is too hard, the vulcanisation is a failure and the joint should be reinsulated.

5. Finish off the joint with 3 half lap layers of single proofed tape the last layer extending 1″ over each side of joint.

Precautions.

1. When applying the rubber the hands should be kept dry and perfectly clean.

2. Special care should be taken that the applied rubber be brought into immediate contact with the prepared ends and that no threads of the original covering or other foreign material intervene between the surfaces.

3. Unless everything is perfectly clean and all air excluded by careful and tight lapping, the joint may be found to have blown even though the rubber be properly vulcanised.

4. If during vulcanisation the temperature should drop to say 280° F., the curing should last for half-an-hour instead of 20 minutes, but it is important that the temperature should be kept as constant as possible between the limits of 290° and 300° F.

5. Any benzole used should be of the best quality. A little of it may sometimes be required to moisten the vulcanising solution, should the latter at any time become dry through exposure to the air. The benzole should be used with great care as it is most inflammable.

NOTE.—Vulcanising will not usually in future be resorted to for insulating the joints. A method of insulating similar to that used for joints in the Submarine Mining Service will be employed.

CHAPTER XV.

DIRECTING SEARCHLIGHTS.*

It is a well established fact that to obtain the best results from a searchlight, the observer must be at some considerable distance from the projector. In the case of searchlights, which it is intended to use as movable beams, this necessitates the existence of some means of communication between the observing station and the searchlight emplacement.

The Service equipment for this purpose consists of an electrically controlled dial, calibrated in degrees for horizontal training, and an electro-motor for vertical movement, controlled by a switch.

In addition, telephonic communication is supplied. The whole arrangement, with list of stores, &c., necessary, is clearly indicated in the "Instructions for the Permanent Installation of Searchlights for Coast Defence," which is given in full at the end of this chapter.

There may also be found at stations where the above arrangement is not supplied an older form of directing apparatus, now obsolescent, known as "Indicator, directing searchlight."

The receiving portion (Fig. 113) of this apparatus, which is used at the light station, consists of a wooden box about 13 inches square and 5 inches deep, divided into four compartments, each containing a 60-volt 16-c.p. incandescent lamp. The front of each compartment is of glass, on the inside of which is pasted a paper with the words "elevate," "depress," "right," and "left," printed reversed on the inside. When any lamp is lit one of these words is clearly seen from the front. The four terminals on the top of the box marked "elevate," "depress," "right," and "left," are each connected to one terminal of the lamp in the corresponding compartment; the other terminals of each lamp is connected to the fifth, or general terminal, marked O.

A single stroke bell of low resistance is used in connection with the box of lamps to call the attention of the man who is to use the light. It works with the current for one incandescent lamp. It has two gongs, so as to ring both on make and break of circuit. Clips to hold a fuse wire are attached to it, and a fuse to cut out at about 4 amperes inserted; two ·003-inch platinum wires would be suitable.

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* Note.—Defence electric lights may conveniently be divided into: (i) Fixed diverged beams, (ii) Diverged beams capable of traverse, (iii) Fixed concentrated beams, and (iv) Concentrated beams capable of traverse. The word searchlight may be occasionally usefully employed in lieu of the expression defence electric light, more particularly when referring to details of the electrical circuits concerned, as here and elsewhere.

The transmitting portion consists of four keys mounted radially on an insulated base.

INDICATOR, DIRECTING SEARCHLIGHT.

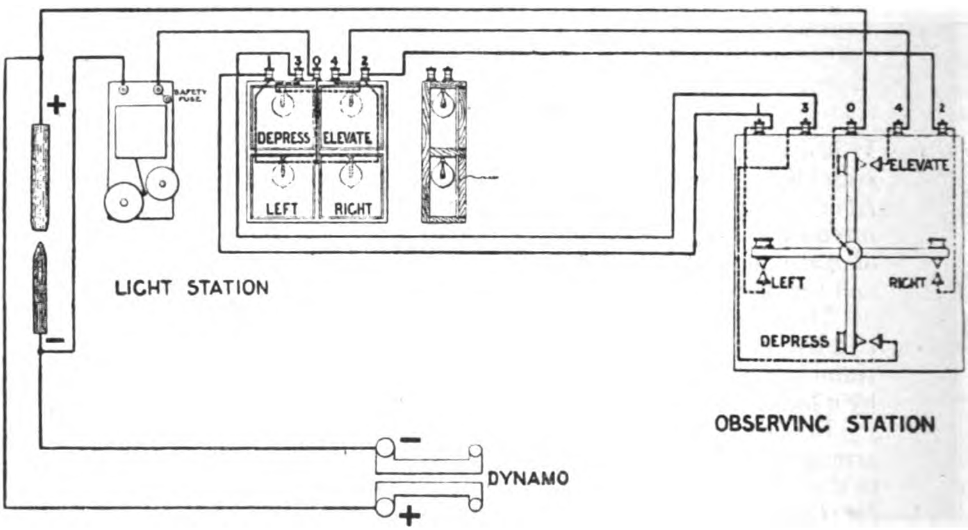


Fig. 113.

The keys are connected together at the centre, which is connected to a central terminal on the base, the bottom contact of each key being connected to a separate terminal. The keys are named to correspond with the lamps they actuate, and the connections are as shown. This equipment should be supplemented with telephones.

Use of Motor and Dial.

As shown in the diagram accompanying the W.O. instructions before mentioned, the motor switch is under the control of the observer; the field of the motor is kept constantly excited in one

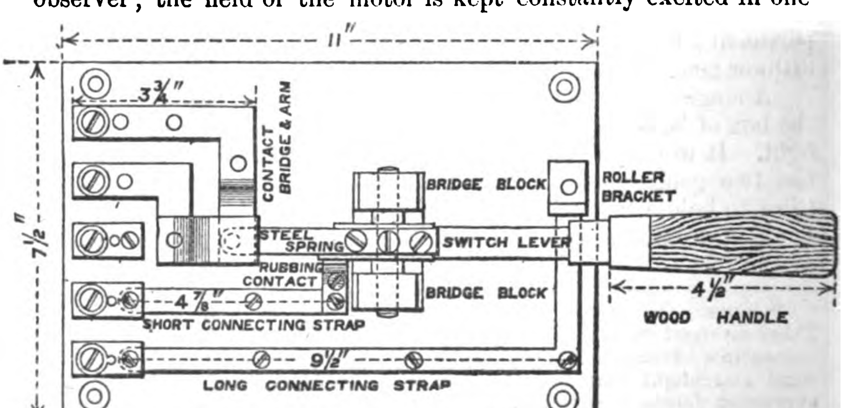
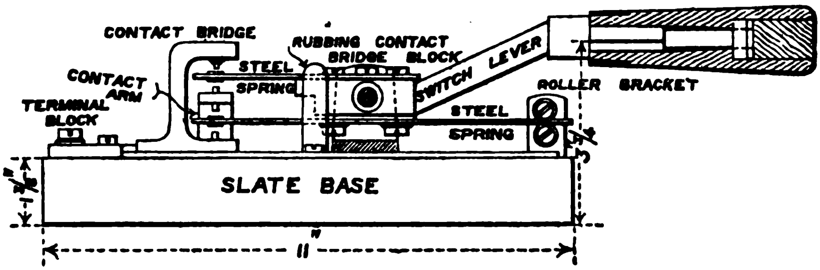


Fig. 114.



Elevation.—Front of bridge block removed.
Fig. 115.

direction off the lamp terminals, and the armature current can be reversed by means of the switch.

The switch is mounted on a slate base, 11 inches by 7½ inches.

The switch lever is constructed somewhat in the manner of a Morse key. It has three positions, and acts as a reversing key in the upper and lower positions, the intermediate position being that of rest, in which the circuit is disconnected.

Five terminals are provided—two being for wires leading to armature of motor, two for wires connected to source of power, and one for use in conjunction with negative-power wire for the insertion of a wire fuse.

In connection with this switch is used a resistance for regulating the speed of the motor. It is known as "Frame, resistance, 2·5 amperes 23 ohms," and is shown in Fig. 116.

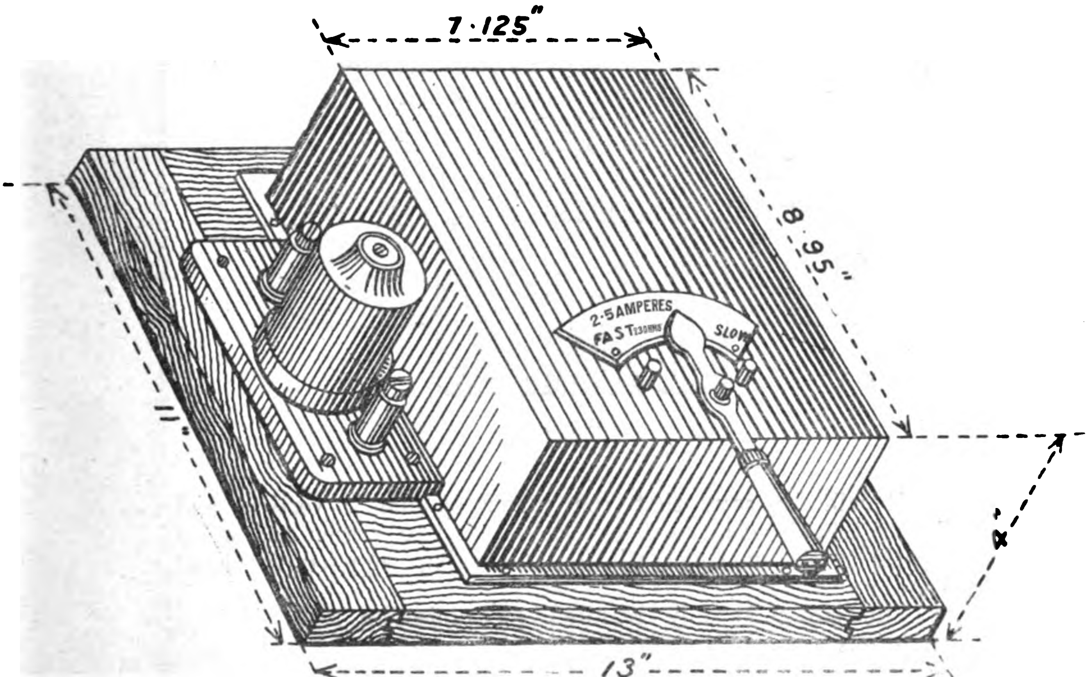


Fig. 116.

The attachment of the motor to the projector is shown in Fig. 117.

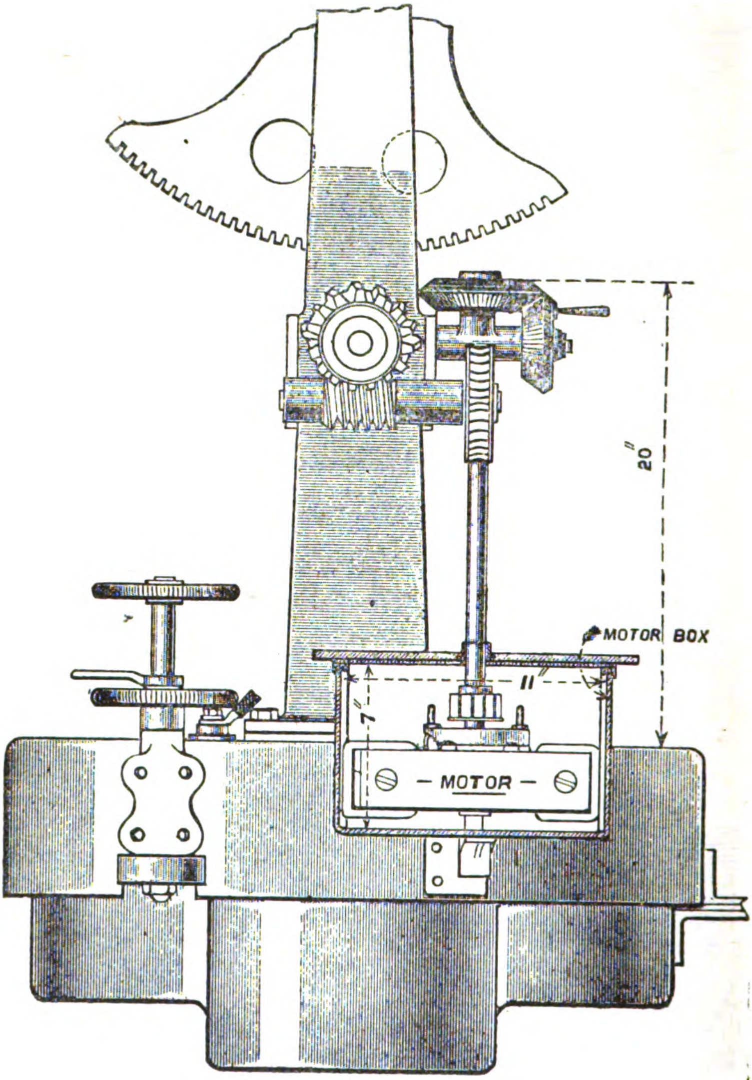


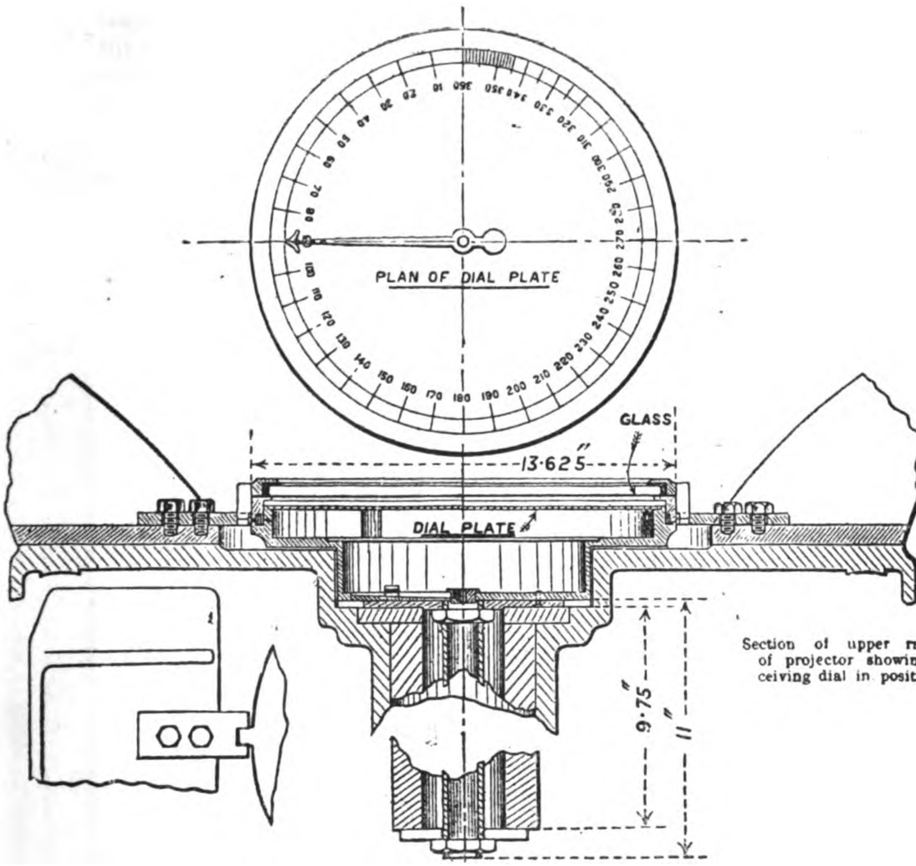
Fig. 117.

It will be seen that the motor spindle is vertical and drives the elevating arc by means of two worms and worm wheels as shown, bevel wheels also being supplied for hand working.

The motor is only required for projectors fixed in high situations.

Dials.

These are known as "Dials, electric, receiving, with tube and nut," and "Dials, electric, transmitting, with handle." The receiver is fixed on the projector body as shown in Fig. 118. The bevel ring is free to revolve on the case and is provided with two lugs to fit brackets on the projector, and a mark is provided inside the bezel ring to enable the operator to follow, with the projector, the movements of the dial needle.



Section of upper raceway of projector showing receiving dial in position.

Fig. 118

The dial depends for its action on the movement of three pallets engaging in a toothed wheel. The action will be readily understood from Fig. 119, where a rack is substituted for the wheel and the pallets are shown as wedges and numbered 1, 2, 3. Each tooth is divided in the diagram by fine lines into six parts, and it will be noticed that while No. 1 pallet is opposite the bottom of a tooth, No. 2 is two teeth plus two-thirds of the side of a tooth further

to the right, and No. 3 two teeth plus two-thirds further, *i.e.* one-third down the opposite side, having passed the point.

If now No. 3 pallet be caused to engage, the rack will be moved to the left a distance equal to one-third of a whole tooth; this will bring No. 2 pallet into the same position relative to a tooth as No. 3 occupies in the drawing, and No. 1 into the same relative position as No. 2 in the drawing. If now No. 2 be caused to engage, the rack will move further to the left and No. 1 will be in a position to continue the motion.

Hence, if the pallets are made to engage the rack in the order 3, 2, 1, 3, 2, 1, the rack will move to the left by movements equal to one-third of a tooth at each engagement. A similar argument will show that if the pallets be caused to engage in the order 2, 3, 1, 2, 3, 1, the rack will move to the right. In practice the rack is replaced by an 8-toothed star wheel and the pallets by small rollers as shown in Fig. 120, and the motion is suitably geared

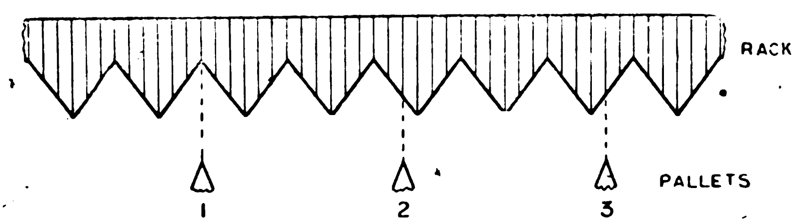


Fig. 119.

so as to cause the pointer to move one degree per impulse. The small switch shown at the top of the transmitting portion is an arrangement by which the battery circuit is broken at the positions of rest of the handle.

These impulses are sent from the observing station by means of a "Dial, electric, transmitting," which, according to which way the handle is turned, completes the circuit through the three electro-magnets shown in Fig. 120 in such an order as to cause the pallets to engage in the order 3, 2, 1, or 1, 2, 3. The transmitter has a pointer mechanically geared to the handle and moving over a dial similar to that of the receiver. The two needles should, of course, read the same; this can be effected by moving the bezel ring of the transmitting dial until the reading agrees with the ascertained reading of the receiving dial. It is usual to place in the common return wire the ·2-ohm coil of a Q. and I. galvanometer, in order to show whether the circuit is broken. As the pointer of the transmitter is mechanically geared, it, of course, moves whether the currents are on or not and affords no guide by which to observe a failure of current.

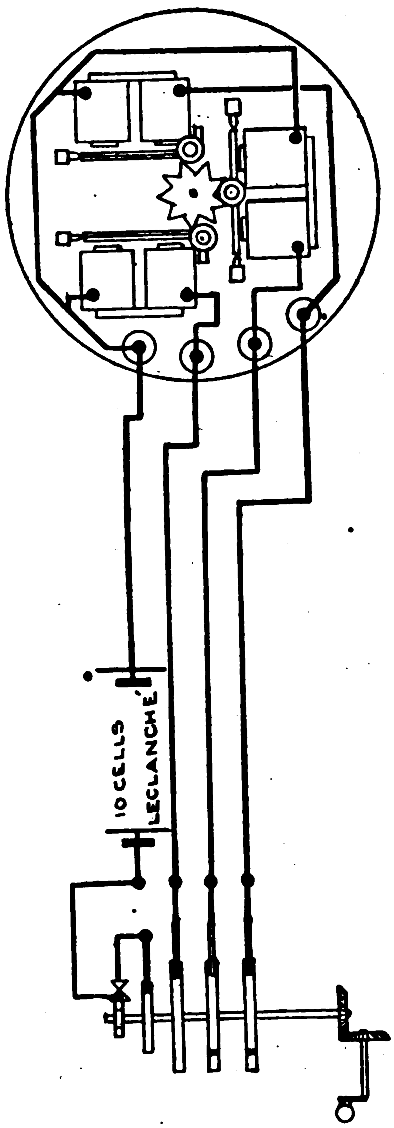


Fig. 120.

Instructions for the Permanent Installation of Search Lights for Coast Defence.

Number and description of circuits.

1. The type diagram shows the number and arrangement of conductors necessary for operating and directing the light.

Exclusive of cables for the working of a second beam from the same engine room, of any additional telephone circuits required in connection with the approved system of command lines, and of spare wires, these consist of—

Between engine room and emplacement.

2 suitable for 150 amperes of current.
2 to supply current to incandescent lamps.
2 for telephone circuit.

Between engine room and directing station.

2 suitable for about 30 amperes of current for motor circuit and incandescent lamps.
2 for telephone circuit.

Between directing station and emplacement.

2 for elevating motor.
4 for traversing dial.
2 for telephone circuit.

Method of laying cables.

2. The cables and wires to be used may be either armoured and laid direct in the ground without other protection, or they may be drawn into pipes. Generally speaking, armoured cables will be used at stations abroad, except where the route, which the wires are to follow, is such that it is desirable to establish a drawing-in system on account of cost or difficulty of access for purposes of repair. This may occur, when, for the sake of protection, it is found necessary to bury the wires at an excessive depth, or when they are run under buildings, or under pavements which would require to be broken up to obtain access to the conductors.

At home stations the wires would generally be laid in pipes on the drawing-in system.

Description of armoured cables to be used.

3. The description of armoured cables to be laid in the ground are as follows, viz.:—

For current to arc lamp K_5 ($\frac{37}{15}$ strand, lead sheathed and steel taped).

For current from dynamo to directing station for motor and incandescent lamps, $\frac{7}{15}$ strand, lead sheathed and armoured (no Service pattern yet adopted).

For incandescent lamps at emplacement, telephone, motor and dial circuits, L_1 (2 core), L_2 (4 core), L_3 (7 core), and L_4

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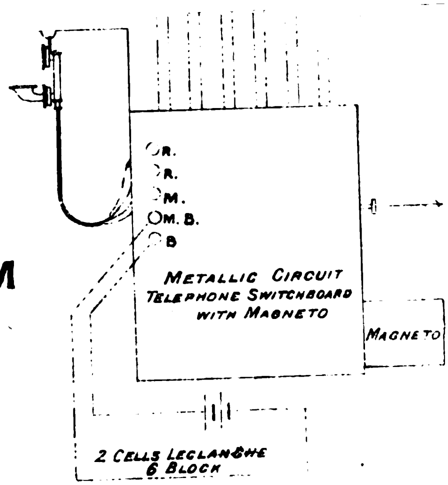

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(9 core) cable should be used according to requirements, or as may be available. These are all $\frac{3}{20}$ strand, lead sheathed and armoured. Where practicable one type only, viz., L_3 should be employed.

Description of conductors to be used.

4. For drawing into pipes the following are suitable:—

For current to arc lamp C_7 ($\frac{37}{16}$), or K_4 ($\frac{37}{16}$).

For current from dynamo to directing station for motor and incandescent lamps C_{10} ($\frac{7}{15}$).

For incandescent lamp at emplacement, telephone, motor, and dial circuits, C_{17} ($\frac{1}{16}$).

The above are all single conductors, insulated vulcanised rubber and braided.

K_4 is also lead sheathed.

Resistance of circuits.

5. It should be noted that the sizes of cables or wires to be used should in all cases be regulated by maximum permissible resistance. These are as follows, viz.:—

Main cables (150 amperes), ·0066 ohm for each volt above 60 at terminals of dynamo.

Circuit from dynamo to directing station for motor and incandescent lamps, $\frac{1}{2}$ ohm.

Circuit from dynamo to emplacement for 16-candle-power incandescent lamp, 1 ohm for each volt difference of potential between the pressure at terminals of dynamo, and pressure required at lamp terminals.

Circuit from directing station to emplacement for motor 6 ohms.

Dial circuit 6 ohms.

In all cases the resistance is to be taken as that of both line and return wire added together.

The diagram shows the arrangements under normal conditions.

Method of laying pipes.

6. When armoured cables are not used, all cables and wires outside buildings should be laid in earthenware or iron pipes, with drawing-in boxes at intervals, in the manner described in Preece and Sivewright's "Telegraphy," or Stewart Russell's "Electric-Light Conductors."

The pipes (or armoured cables) should be laid at such a depth as not to be liable to mechanical injury by traffic, and should as far as possible be protected from an enemy's fire. Where liability to heavy wheeled traffic exists, earthenware pipes should not be less than 3 feet, or iron pipes not less than 2 feet below the surface. Protection from fire should wherever possible be secured by the selection of a sheltered route. It is not possible without incurring undue expense to provide against the effect of a high-explosive shell bursting immediately over the cables, but burying at a depth of 1 foot will afford sufficient protection from splinters.

Earthenware (glazed) may preferably be used, except where heavy traffic indicates that iron would be advisable.

Iron pipes should be of cast-iron with socket joints, carefully jointed and water-tight. Glazed stoneware drain pipes are suitable

for the earthenware pipes and should be jointed with Portland cement (1 cement, 1 sand).

7. The pipes should be not less than 3 inches internal diameter, smooth internally, carefully laid in a perfectly straight line from point to point, with a suitable fall to a convenient point for drainage.

Between the engine room and the emplacement, the line of pipes should preferably be double, one line containing the two 150-ampere cables, and the other the small wire. When this is not practicable, the pipes throughout this section should be not less than 4 inches internal diameter.

The pipes must be examined before being laid to see that the interior is smooth. During the process of laying, a stout wire must be left in them to enable the interior to be scoured out by means of a stiff wire brush, in case cement should have come through the joints, so as to obstruct the cable when being drawn in.

The scouring process should be carefully performed as the pipes are laid, and before the cement has had time to set.

8. The drawing-in boxes should be placed at every change of direction and at intervals not exceeding 50 yards in the straight. They may be of brick or concrete. If the pipes are laid 3 feet deep, or less, the drawing-in boxes may be brought up to the surface and covered with a cast-iron plate (inside dimensions 2 feet by 2 feet), or a stone set in a cast-iron or concrete frame.

If the pipes are laid more than 3 feet deep, the drawing-in boxes should be 2 feet by 3 feet in plan, internally 1 foot 6 inches deep, covered with a stone slab and buried.

In all cases suitable means of lifting covers, by rings or otherwise, should be provided. The positions of all boxes, whether on the surface or buried, should be recorded on an accurate site plan.

9. The wires should be drawn through in both directions from a central point, and all the wires required to be laid in one pipe should be drawn in together.

Joints in conductors.

10. All joints in the wire outside the building should be avoided. Where unavoidable, they should be situated at a box, and not drawn into the pipes.

11. Joints in buried armoured cables, where it is found impossible to avoid them, may either be vulcanised or be made with tape and solution, protected by a lead sleeve, the cable being spliced or enclosed in a submarine mining connecting box.

In such case a careful record should be kept of the point at which the joint occurs, so that it may easily be uncovered if necessary.

Internal wiring.

12. All unarmoured wires inside buildings should be enclosed in wood casing; the use of staples or holdfasts to secure these wires should be avoided.

Cut-outs.

13. The ends of all wires except the telephone circuits in engine room are shown as connected to four way fusible cut outs. These afford a ready means of disconnecting the circuits for testing or localising faults, and also protect them from damage through excess of current.

The fuse to be used should be made of No. 18 S.W.G. tin wire.

Connections of incandescent lamps.

14. Independent leads for incandescent lamps must, when these lamps are employed, be run from the dynamo terminals, as shown in the diagram.

Lamp leads should not be taken off the mains, as the lamps would be subject to a large variation of voltage. The voltage of the lamps should be less than the running voltage at the terminals of the dynamo, a resistance being added to absorb the surplus pressure.

Telephone circuits.

15. Telephone circuits should be provided between the directing station and emplacement, between directing station and engine room, and between emplacement and engine room. A switch and extra bell should be fixed at each place to obviate the necessity for duplicating the telephone apparatus. When more lines of telephonic communication than those above mentioned enter the directing station, it may be desirable to provide some form of telephone switch-board, either in addition to, or instead of, the switch. Where it can be arranged, it is desirable that the engine room telephones should be fixed not in the engine room itself, but in a neighbouring recess, where the working may not be interfered with by the noise of the engines.

All circuits must be metallic, having a thoroughly insulated return wire. Care should be taken to lay them, when practicable, in a manner as non-inductive as possible by selecting cores in the same cable and situated diametrically opposite to each other to form the line and return respectively.

Telephones may be used either with trembling bell and battery or with polarised bell and magneto-generator. The latter are preferable.

Dial apparatus.

16. The dial apparatus consists of a transmitter and receiver. The former is fixed in the directing station, the latter in the well of the projector. Before securing the dial by the nut on the tube it should, where practicable, be aligned, so that when the pointer reads zero, the beam shall be directed to the true north.

The wires on the dial are numbered 1, 2, 3, and 4, and should be connected to terminals similarly numbered on the transmitter.

No. 4 is a common return wire.

The quantity coil of a detector should be connected to No. 4 circuit and fixed at the directing station.

When at rest the handle of the transmitter should be vertical, either up or down, and the detector should indicate that no current is passing.

A battery of ten 6-block Leclanché shells should be connected to No. 4 terminal. The direction of current is immaterial.

To adjust the transmitter to read with the dial the circuit should be disconnected, the pointer of the former brought to the required reading, and the circuit again made.

It will sometimes be found that on revolving the handle of transmitter after completing the circuit the dial commences by losing or gaining one division. Under these circumstances, in adjusting the pointer of transmitter, it should be brought either one step beyond or short of the required reading, as may be necessary, before completing the circuit.

Detail of Stores required for Search-light Emplacement with Directing Station.

No. of §, List of Changes.	Designation of Article.	Number or Quantity. Emplacement.	Directing Station.	Engine Room.	Total.	Remarks.
	Electric Light Stores, Section 28.					
8978	Ammeters, 200 amperes	1	...	1	2	
	Carbons, horizontal lamps—					As may be authorised
8604	Negative, 26·5 mm.	...	...	...	...	
8604	Positive, 38 mm.	...	...	...	...	
	Cut-outs, fusible—					
	Four-way, 10 amperes... ...	3	3	1	7	
	Double-pole, 5 amperes ...	1	...	1	2	
	Fittings, incandescent lamps—					
	Brackets, ship pattern... ...	1	1	...	2	⅜-inch nipple
	Holders, lamp, plain	1	1	...	2	For B.C. lamps, ⅜-inch socket
	Frames, resistance—					
7992	200 amperes ·25 ohm	...	...	3	3	
	2·5 amperes 23 ohms	...	1	...	1	For motor circuit
	Fuze, wire, 5 amperes lb.	⅓	⅓	⅓	1	
	Generators, electric, continuous current, 16 unit	...	...	1	1	
8637	Glass strips, 3/16 inch by 3¾ inches by 37⅞ inches	5	...	...	5	For repair of projector doors
5794	Glasses, framed, coloured ...	1	...	...	1	
	Lamps, electric—					
8129	Arc, horizontal, automatic, 120 to 150 amperes	1	...	...	1	
8429	Accessories ... ... sets	1	...	...	1	
	Incandescent, 60 volts, 16-candle power	2	2	4	12	B.C. pattern; includes 4 spare
8430	Lenses, 90 cm., diverging—					For use of search light as a fixed beam
	16 (30 or 45) degrees	...	...	...	...	As may be authorised
	Prisms, letter*	...	...	...	...	As may be authorised
8978	Lugs, terminal—					As required
	3/8-inch	...	...	...	...	For 19/18 or 7/14 strand
	½-inch	...	...	...	...	For 7/16 or 7/18 strand
	Powder puffs	1	...	...	1	
8663	Projectors, 90 cm. (Mark III)—					
	Bodies	1	...	...	1	
	Bedplate	1	...	...	1	
	Dials, electric—					
	Receiving	1	...	...	1	
	Transmitting	1	...	...	1	
	Doors, glazed	1	...	...	1	
	Frames, reflector	1	...	...	1	
8663	Lugs, terminal—					
	Large	2	...	...	2	
	Small	2	...	...	2	
	Pedestals, hand or motor elevating	1	...	...	1	
	Plates, graduated	1	...	...	1	
	Spanners, box—					
	½-inch	1	...	...	1	
	¾-inch	1	...	...	1	
	Flat 5/8-inch	1	...	...	1	
	Trays, lamp	1	...	...	1	
	Reflectors, glass, silvered—					Pattern as may be decided
	Mangin 90/45 cm.	1	...	...	1	
	Paraboloid 90/42 cm.	(Mangin or Paraboloid)				
	Switches, electric light—					
7991	Automatic	...	...	1	1	
8063	Motor, directing	...	1	...	1	
7908	Single pole, 200 amperes ...	1	...	1	2	
	10 amperes	1	1	...	2	
	Voltmeter, one way	1	...	1	2	
	Terminals, electric light, double—					
	3/8-inch	...	...	2	2	
	½-inch	...	...	2	2	
	Voltmeters—					
8505	Electro-magnetic, 80 volts ...	1	...	...	1	
8505	Hot wire, 120 volts (Mark II)...	...	...	1	1	
	Wires, covered—					As required
4935	C_5	...	...	...	...	For internal circuits
	C_7	...	...	...	...	For internal circuits
	C_{17}	...	...	...	...	For internal circuits

* State distinguishing letters of prisms in demands (see List of Changes, § 8130).

DETAIL of Stores required for Search-light Emplacement with Directing Station—continued.

No. of §, List of Changes.	Designation of Article.	Number or Quantity. Emplacement.	Directing Station.	Engine Room.	Total.	Remarks.
	Electric Light Stores, Section 28—*contd.*					
	Wires, covered—*continued.*					
	C_7	...	...	...	...	For external circuits
7913	C_{16}...	...	...	...	...	For external circuits
	C_{17}...	...	...	...	...	For external circuits
8847	K_4	...	...	...	...	For external circuits
8847	K_5	...	...	...	...	For external circuits
	Wire, uncovered—					
	Z 20 ... ... oz. troy	...	...	...	2 20	Repair of hot wire voltmeters
	Z 21 ... ... "	...	...	...	2 20	Repair of hot wire voltmeters
	Stores for Land Cables, Section 28.					
	Tubing, lead ½-inch	...	...	...	...	As required
	Cables, electric—					
	L_1 (2 core)	...	...	...	...	As required
	L_2 (4 core)	...	...	...	...	As required
	L_3 (7 core)	...	...	...	...	As required
	L_4 (9 core)	...	...	...	...	As required
	Telegraph Apparatus, Section 29.					
8673	Batteries, Leclanché, 6 block, open	1*	11†	1*	13	
7028	Bells, polarized	1	1	1	3	
8673	" " extension ...	...	...	...	...	As required
8673	Connectors, wing nut	1	2	1	4	
	Galvanometers, detector—					
	Quantity and intensity ...	...	1	...	1	For dial circuit
8240	Plates, earth telegraph (Mark II)	...	...	...	...	As required
	Switches, telephone, intermediate, metallic circuit	1	1	1	3	Post Office pattern; not a Service store
8294	Telephones, operators	1	1	1	3	

* For microphone.
† Includes 10 cells for dial.

CHAPTER XVI.

ACCUMULATORS OR SECONDARY BATTERIES.

If two plates of lead be taken and immersed in a sulphuric acid solution, and a current passed through them, after a certain length of time the plate which was connected to the positive pole of the source of power will be found to have changed colour to a blackish purple tint. Examination will show this to be due to a coating of peroxide of lead. The plate that was attached to the negative pole will be found to have undergone practically no change.

If now the lead plates be connected through a conductor, it will be found possible to obtain from them a current for a certain length of time, this product "current (average) × time" thus obtained being dependent on the product "current (average) × time" put into the cell in the first instance.

The first time the plates are so treated the amount of current that can be taken out is small, owing to the plates not having been properly "formed," as it is termed.

This *forming* consists in forcing a current through the cell, sometimes reversing it and taking current out, which processes occupy a great length of time. The object in this is to obtain a spongy surface of pure lead on the negative plate. At each successive "charging" the peroxide on the plate attached to the positive pole of the source of the current sinks a little deeper into the metal. This "eating-in" operation goes on until there is a sufficient thickness of oxide to protect the lead from further electrolytic action.

In all cells of the "*Planté*," or *solid plate*, type this method of "forming" is adopted. In practice it takes a long time to properly form the cell; the operation cannot be hurried, as excessive current during forming produces brittleness and buckling of the plates.

This, then, is one type of secondary cell, of which there are many patterns, the chief object in all improvements being to make the plates porous yet strong, so as to offer a large surface to the electrolyte.

The other type of cell is termed the "pasted-plate" type, due to "Faure," who, seeing the inconveniences due to the electrolytic method of forming plates, conceived the idea of accelerating their formation by applying a coating of chemically prepared oxide of lead to their surfaces and converting it into active material by the action of a current.

To effect this he coated the plates with lead oxide, "minium," or "litharge," made into a paste with acidulated water. These plates are then subjected to a current which transforms the paste

on the positive into peroxide of lead, and that on the negative into porous pure lead.

Of these two main classes of secondary cells, the solid and pasted types, there are a great number of different makes. They consist of various numbers of plates of various sizes, according to the work they are called upon to perform, the number of plates always being odd, *i.e.* one more negative than positive plate. The reason of this is that, when in use the positive plate is that which is most difficult to keep in good order, and if the number of plates in the cell were even, there would be one positive plate with only one side active, which would be almost certain to lead to buckling of the plate.

As a general rule, for recent plates the maximum output and charging current for a cell is about 8 amperes per square foot of positive plate surface, but the exact amount varies with the different makes of cell. The discharge rate is, as a rule, higher for the solid lead plate type than for the pasted type (*i.e.* a heavier current can be taken out without damaging the cell), but the storage capacity, *i.e.* the product current × time, or ampere-hours is, as a rule, less, weight for weight.

Hints on Setting up a Battery of Cells.

[*Note.*—Everything should be ready for the cells before the plates are obtained, as they are, as a rule, partially formed, and will "sulphate" (explained later) if left exposed to the air too long. Should the maker's instructions for erecting a battery of their cells differ in any way from the following, they should be followed in preference to these.]

Upon obtaining the cells, the plates should be put into their boxes dry and properly connected up. Then having everything ready to start charging and having tested the polarity of the dynamo, the electrolyte may be added, but it is important that no time should elapse between adding the electrolyte and starting the charge. (The electrolyte should have a specific gravity of 1·190; it should be all mixed in readiness and allowed to cool, and when poured in should come about 1-inch over the top of the plates.)

The initial charging should go on for 36 hours if possible, but on no account should it be stopped for the first 12 hours, and no current should be taken out of the cells until the electrolyte in every cell has turned milky in appearance and the s.g. has risen above 1·200. This milky appearance is due to gas being liberated in quantity from the plates.

The s.g. of the acid will drop after being put into the cell, and may not commence to rise for a considerable time after charging has started.

When the cells are in use, it is necessary to recharge them whenever the s.g. of the electrolyte falls to 1·180. On no account whatever should the E.M.F. of a cell be allowed to fall below 1·9 volts. (The normal E.M.F. of a cell is as nearly as possible

2 volts, although after charging it may be for a short time up to 2·3, but this extra voltage quickly disappears).

In charging, a *full* charge should always be given. Nothing tends to destroy the plates more rapidly than partly charging the cells and then exhausting them.

Method of Starting a Charge.

Before the battery is switched into circuit, care should be taken that the field magnets of the dynamo are of proper polarity. This may be ensured by raising the brushes of the dynamo while it is at rest, and turning the cells on to the shunt coil for a short time, which will magnetise the field magnets in the proper direction for charging. [This can only be done safely with a small dynamo. In a large one the insulation of the shunt coil may very possibly be damaged on breaking the circuit unless a bye-path of some sort is introduced for the shunt coil to discharge itself through. With the Service 16 unit dynamo it may, however, be

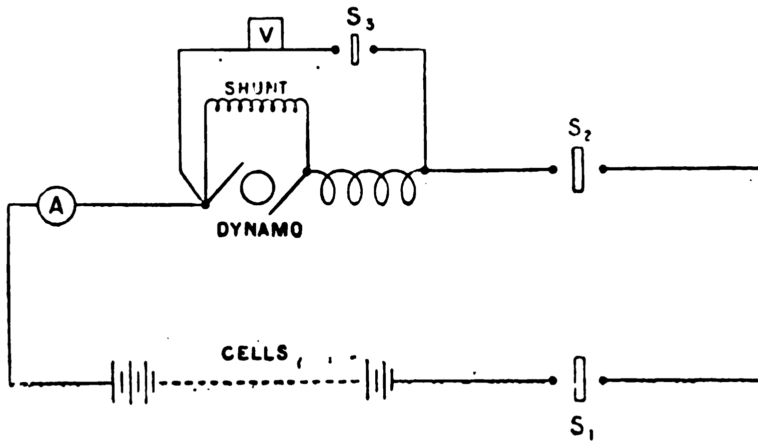


Fig. 121.

done fairly safely, but it is advisable to use a bye-pass.] The procedure usually adopted is as follows:—

The cell attendant having ascertained from the dynamo room that the brushes are up, closes S_1; the attendant in the dynamo room then closes S_2 and S_3; he notes the volts on the voltmeter V and opens S_3 and then S_2 (if S_2 be opened first the discharge from the shunt coil will probably damage the voltmeter).

Now starting up his engine he lowers the brushes and closes S_3 again, and when the volts have risen about 5 per cent. above their previous reading, closes S_2 and looks at his ammeter A and then adjusts his engine speed till the current is correct.

When stopping he slows his engine until the current is about 10 amperes and then opens S_2.

The proper rate of charge, of course, varies with the type of cell in use. The makers of secondary cells when supplying a

battery, as a rule, issue a card bearing certain instructions as regards rate of charge, which should be adhered to.

On no account must the dynamo be stopped before switching out the battery. Should this be done the battery will endeavour to run the dynamo as a motor, and may furnish an injuriously large current for a short time. Special switches (polarised) can be obtained which render this impossible.

During charge, should a cell in the battery not "boil" with the others, it should be carefully examined for pieces of paste or scale sticking between the plates and so short circuiting the cell; if found these should be carefully removed with a piece of wood (not metal) and the cell cut out during discharge by disconnecting it and bridging over the gap with a suitable conductor, always, however, reinserting the cell during charging; after a few charges without discharge the cell will probably be found to have recovered.

SULPHATING.

Should the cells have received rough usage, such as over-discharge, or excessive current discharge, or should they have been allowed to stand too long, "sulphating" will probably ensue.

This consists of a sort of mouldy growth on the positive plates of a greyish colour, or of a sort of scale of a venetian red colour, and sometimes of a white scaly deposit on the negative plates.

This action should at once be checked or the life of the cells will be shortened. Its effect is to render parts of the plates inactive and consequently to overwork the rest. The results of bad sulphating are scaling, falling out of paste, buckling, and short circuiting.

The cure is prolonged charging at low rates, about half normal charging rate to start with, which will gradually reduce the unhealthy sulphate to a better form and eventually charge the plates by the conversion of $Pb\,SO_4$ to $Pb\,O_2$.

This is a tedious business, but must not be hurried, or the positives will buckle. Most of the white sulphate will fall off in scales, and may perhaps stick between the plates, in which case it must be at once removed with a flat stick of wood or ebonite.

In mixing the electrolyte for a cell, or replenishing after evaporation, distilled water should be used, or failing this *clean* rain water. Should the s.g. of the electrolyte fail to rise to 1·200 when the cell is charged, add electrolyte of 1·300 s.g. to bring up to strength, having first made sure that a prolonged charge at a low rate will not cause the electrolyte to reach its proper s.g.

On no account add neat acid or the plates will rot. All additions should be made when the electrolyte is "boiling."

Secondary cells in order to remain in good health must be exercised regularly and not too violently, *i.e.* they must be charged and discharged with moderation. Should cells unavoidably have to stand idle for any length of time they should be given a full charge to begin with, and should be periodically recharged, say once a fortnight, until they "boil" in order to keep them in health.

Arrangement of Accumulators in Circuit.

Accumulators may be used with any system of distribution which admits of their regular charge and discharge. In the circuit shown on Plate XVI, a very common arrangement in small installations, it will be seen that the house lighting may be done from the dynamo or accumulators, or both together, or the cells may be charging while the lighting is being done.

In order to allow of proper voltage at the lamps it is obviously necessary to have some arrangement by which an extra cell or two may be thrown in or cut out as required, according to the requirements of the load. This is effected by a step switch such as is shown in Plate XVI, marked "discharge."

The cells which can be thrown in or out are usually called "make-up" cells. As these will not have such heavy duty to perform as the remainder of the battery, they will be fully charged before the remaining cells come up. Another step switch (marked "charge") is therefore provided to enable them to be cut out as they rise.

A shunt-wound dynamo is shown, as when the work consists of charging accumulators only this form is preferable.

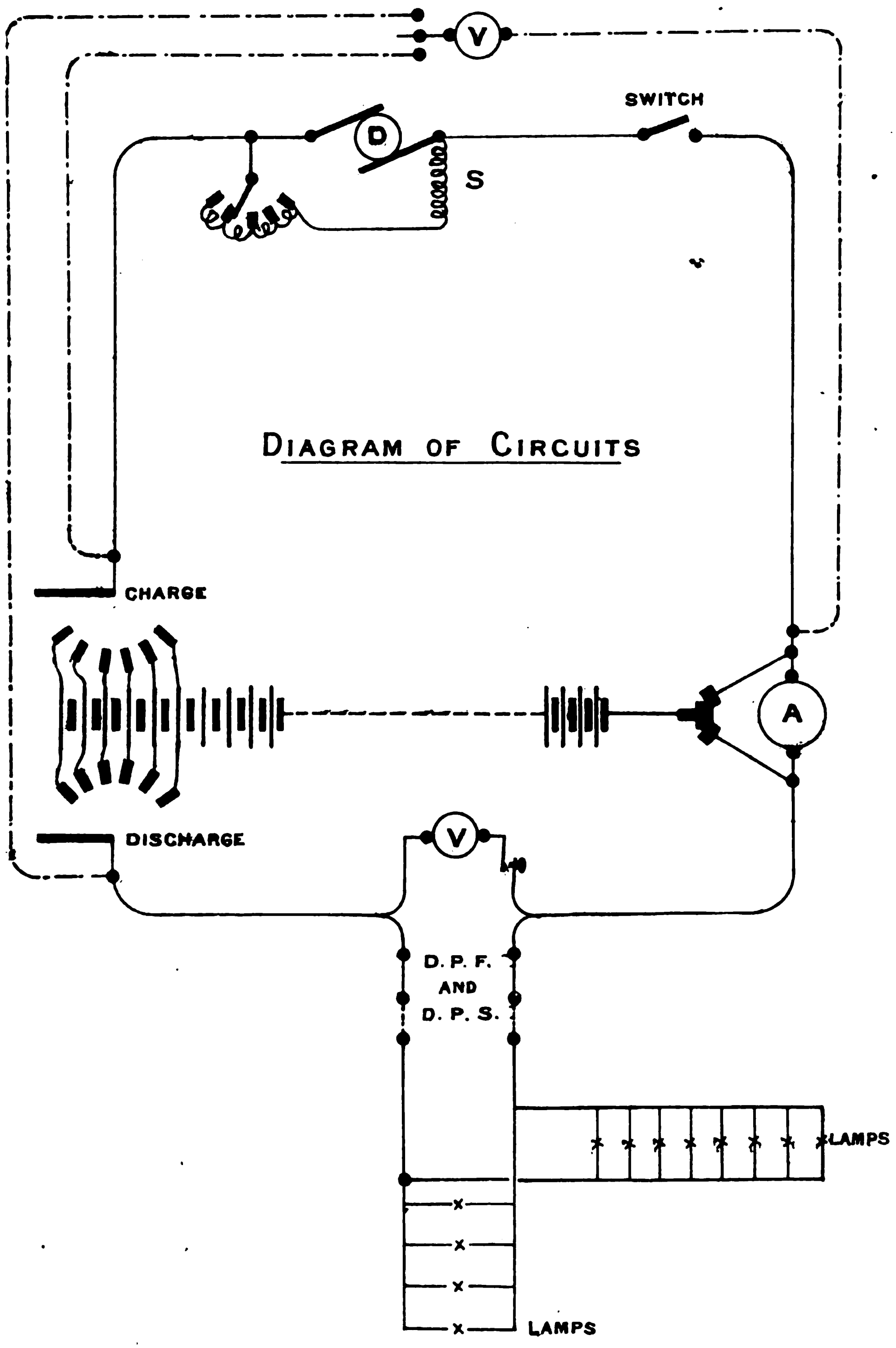
A switch and resistances are shown in the shunt circuit of the dynamo. This is to enable the engine driver to vary the volts, since the volts necessary at starting when the cells are at, say, 1·9 apiece, will obviously not suffice when the voltage per cell has risen to, say, 2·2.

As the diagram is drawn it will be seen that the voltage on the lighting can be read at all times, and on the ammeter can be read the current when the cells are being charged or discharged; but when the lighting and charging are going on together, only one can be read at a time. Of course, a preferable arrangement would be to have two ammeters, and also another voltmeter for the dynamo, or to use the alternative voltmeter arrangement shown in chain-dotted lines.

D.P.S. is a double pole switch on the lighting circuit, and D.P.F. a double pole fuse or cut out.

In the accumulator room the floor should be of lead sheeting or glazed bricks. All woodwork should be coated with some preservative, such as "anti-sulphuric enamel." The instruments in connection with the accumulator room should be kept at a sufficient distance to ensure the acid spray not getting at them. For the same reason the leads in the accumulator room may advantageously be left bare and run on insulators, as any ordinary insulating covering quickly deteriorates under the action of the acid spray. The cells should be so placed as to be easy of access, and the room should be well ventilated, as the gases given off by the cells form, when mixed with air, an explosive mixture; while charging, the windows should be open. The cells may be connected together by lead burning the lugs, but if this cannot be done, brass bolts and nuts are usually employed. These should be coated with vaseline.

ACCUMULATOR INSTALLATIONS.



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CHAPTER XVII.

INCANDESCENT LIGHTING.

THE rapid increase of this method of lighting in the Service renders a short description of it necessary.

A consideration of the various methods of power distribution for incandescent lighting is not called for here. The application of electric light to barrack lighting is not yet on a sufficient scale in the Service to make it necessary to treat more widely of the subject. In the Service the system at present employed is one of continuous currents taken directly from the dynamo or accumulator battery. Let us suppose the power available, and consider how to utilise it.

The lamp consists essentially of a thin carbon conductor, called the filament, enclosed in an air-tight glass globe from which the air has been exhausted to a very high degree. The ends of the filament are secured to two platinum wires melted into the base of the lamp, and the outer ends of these wires are secured to external contacts of some sort, through which a current may be applied to the filament of the lamp. Platinum is invariably used in this connection, as it happens to have the same temperature expansion co-efficient as glass.

Various substances have been tried for the filaments, but at present some form of carbon is invariably used. The various details of lamp manufacture are more or less of the nature of trade secrets, and do not concern us here.

The outer ends of the platinum wires are arranged to form terminals, as before stated, and the lamps are commonly designated by the way in which this has been effected, *e.g.* "Brass collar" or "loop." (*Vide* Plate XIX, p. 198).

The light emitted depends on the temperature to which the filament is raised, and this depends upon the rate at which power is being expended in the filament.

The power required for lamps is proportional to $V \times C$, *i.e.* to $C^2 R$, and the ordinary lamp requires from 3 to 4 watts per candle-power. 4 watts should be allowed for in calculating power for installations.

Taking the above into consideration, we see that a 16 candle-power lamp, properly incandesced, will require about 60 watts, and if run off a 100-volt circuit the current through it will be ·6 amperes, and it will have a resistance at that temperature of about 167 ohms.

In addition to the designation describing the patterns of lamps as regards their external contacts, lamps are further referred to by their voltage (*i.e.* the P.D. which should be applied to them), and their candle power (*i.e.* the candle-power they should emit when their proper voltage is applied, and the measurement is made in the direction in which the candle-power is greatest, *i.e.* generally with the filament square to the observer).

Thus—

$$\left.\begin{array}{l}\text{Lamps, incandescent, B.C., } 50^{v}/16\text{ c.p.}\\ \quad\text{,,} \qquad\qquad \text{,,} \qquad \text{loop, } 100^{v}/25\text{ c.p.}\end{array}\right\}\ \&c$$

Now, the heat generated in a conductor of R ohms resistance is proportional to $C^2 R$ when there is a current of C amperes through it. All solid bodies become luminous at about the same temperature, viz., 550° C., and above 1000° C. the luminosity increases far more rapidly than in direct proportion to the temperature. Carbon is one of the few substances the resistance of which decreases as the temperature increases, and the resistance of a lamp cold (say 15° C.) is about twice its resistance hot (say 1300° C.).

It is evident, therefore, that the current through the lamp will increase somewhat more quickly than in direct proportion to the volts applied. But again, we have seen that the temperature depends on C^2 (about), and the luminosity varies far quicker than the temperature. Hence we should be led to expect some such relationship as that which has been experimentally discovered, viz., that the candle-power varies about as $(\text{volts})^6$ at about the proper voltage.

Hence, in the case of a $100^{v}/16$ c.p. lamp, we get—

$$\begin{aligned}
\text{at } 98^{v}/\text{c.p.} &= \left(\frac{98}{100}\right)^6 \times 16 = 14\cdot0 \text{ c.p.}\\
99^{v}/\text{c.p.} &= \left(\frac{99}{100}\right)^6 \times 16 = 15\cdot0 \text{ c.p.}\\
100^{v}/\text{c.p.} &\quad \ldots \qquad \ldots \quad = 16\cdot0 \text{ c.p.}\\
101^{v}/\text{c.p.} &= \left(\frac{101}{100}\right)^6 \times 16 = 17\cdot0 \text{ c.p.}\\
102^{v}/\text{c.p.} &= \left(\frac{102}{100}\right)^6 \times 16 = 18\cdot0 \text{ c.p.}
\end{aligned}$$

from which the necessity of keeping the P.D. constant is evident. The Board of Trade, to safeguard householders, allow a maximum variation of 4 per cent. at the consumers' terminals from the declared standard pressure.

From what has been said regarding watts per candle-power, it is clear that a 50-volt lamp would require twice the current of a 100-volt lamp of the same candle-power, and since loss of voltage in conductors = C R, if we want to keep the size of mains down, we must reduce C by using higher voltage lamps.

For example, suppose 100, 100v/25 candle-power lamps of 100 watts are arranged all in parallel at the end of two mains, the total resistance of which = R ohms.

Then since current per lamp = 1 ampere, voltage loss in the mains = 100 R volts.

If the lamps were 50 volt, the current per lamp would be 2 amperes, and the voltage loss in the mains = 200 R volts.

Again, supposing the variation in pressure on these lamps is not to exceed 4 per cent., and we consider the lamps divided into 20 groups of 5 lamps each for use as required.

In the case of the 100v lamp, with one group alight, loss in the mains = 5 R, and if V is the pressure at supply terminals, the P.D. at the lamps will be V − 5 R.

With all the lamps alight, P. D. = V − 100 R, and since the difference is limited to 4 per cent., we may write—

$$\left.\begin{aligned} V - 5\,R &= 102 \\ V - 100\,R &= 98 \end{aligned}\right\} \text{ whence } R = \frac{4}{95} \text{ ohms.}$$

With 50-volt lamps, however—

$$\left.\begin{aligned} V - 10\,R_1 &= 51 \\ V - 200\,R_1 &= 49 \end{aligned}\right\} \text{ whence } R_1 = \frac{2}{190} \text{ ohms.}$$

Hence, for the same percentage variation R_1 must be = $\frac{1}{4}$ R.

It would, therefore, appear desirable to increase the voltage of the lamps as far as possible, and to run the lamps in series. With a series arrangement, however, the pressure introduced on to house premises would soon reach a dangerous limit (Board of Trade limit = 250 volts), and also the extinction of one lamp on the circuit would put out all the others unless complications were introduced. At present, as an almost universal practice, all the lamps are arranged in parallel; 100 volts was until recently the most common pressure used, but now the lamps are generally designed for pressures of from 200 to 250 volts.

In designing an installation, calculations must be made for the voltage loss, or "drop," as it is called, and for carrying capacity; the former to prevent fluctuation of light and expense through loss of power, the latter to prevent fire risks through overheating of the mains. Allowing a variation of 4 per cent. (a very high percentage from the point of view of waste through loss of power), and calculating for "drop," will, as a rule, provide leads of ample capacity as regards overheating. Having thus arrived at a suitable size of wire to use, the capacity can easily be checked from any wiring table, but a simple calculation for capacity alone affords no guide as to "drop."

As regards capacity and numerous other details, certain standard rules are laid down by the Board of Trade, and by the Institution of Electrical Engineers, a copy of whose rules is

appended. There will also be found as an appendix to this chapter a copy of W.D. instructions for testing the completed installations.

Calculations for Drop.

It is sufficient to calculate for that branch which has the greatest drop, but it is not always easy to see at first sight which branch fulfils this condition.

A detailed consideration of one or two examples will explain the methods usually adopted.

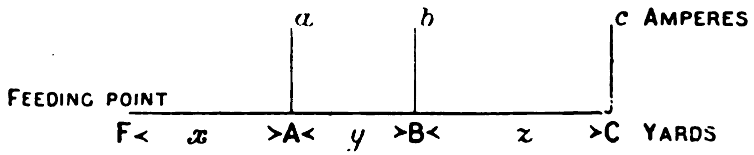


Fig. 122.

Only one main shown.

Drop in F A, due to a amperes through x yards $\propto ax$.
Drop in F B, due to b amperes through $x+y$ yards $\propto b\,(x+y)$.
Drop in F C, due to c amperes through $x+y+z$ yards $\propto c\,(x+y+z)$.
$\therefore$ Total drop between F and C $= [a\,x+b\,(x+y)+c\,(x+y+z)] \times 2\,R$, where R is the resistance in ohms per yard of conductor.

Another method.—

As before:—

Drop in B C $\propto c\,z$
„ A B $\propto (c+b)\,y$
„ F A $\propto (c+b+a)\,x$

$\therefore$ Total drop between F and C $=$

$$[c\,z+(c+b)\,y+(c+b+a)\,x] \times 2\,R$$

as before.

Example.

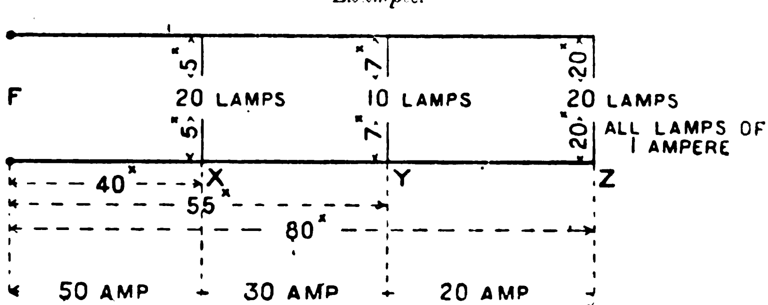


Fig. 123.

At first let us ascertain from a wiring table the sizes of wire suitable for the different portions of the circuit thus :—

F to X = 50 amperes ; suitable size, 19/16

X to Y = 30 amperes ; suitable size, 19/20

Y to Z = 20 amperes ; suitable size, 7/18

Groups X and Z = 20 amperes ; suitable size, 7/18

Group Y = 10 amperes ; suitable size, 3/18.

But the use of many different sizes of wire is unsound, and it will be sufficient to adopt one size for the branches and another for the mains.

Thus for mains maximum = 50α use 19/16, R per yard ·000406.

Thus for branches maximum = 20α use 7/18, R per yard ·00198.

Now drop in branch, Z is obviously greatest and = C R = 20 × 2 × 20 × R (·00198) = 1·584 or say 1·59 volts.

As regards the mains, construct a table thus :—

Reference Point.	Number of Lamps.	Distance from Feeding Point.	L × D.
		Yards.	
X	20	40	800
Y	10	55	550
Z	20	80	1,600
	...	...	2,950

Now this must be multiplied by current per lamp (in this instance 1 ampere) by 2 (for line and return), and by R per yard of conductor in order to obtain the total drop at full load.

$$2950 \times 2 \times R = 5900 \text{ R}.$$

Suppose total drop to lamps is not to exceed 4 volts

Drop in branches = 1·59 volts $\therefore$ drop in mains must not exceed 2·41 volts.

So to find maximum permissible value of R we have 5900 R = 2·41, whence R = ·000408.

Referring to table we find wire suitable 19/16, which agrees with the capacity requirements and is therefore the wire to be used.

Wiring a Building.

The question of how the mains are to be run is a most important one. The point to be aimed at is to secure uniform illumination of all the lamps. If the drop to the lamps be unequal, it is evident that either some lamps must be dim or

some must be "over-volted," in which case their life is greatly shortened. Two plans are commonly met with, the first which we may call the "equal-mains" method is shown in Fig. 124, and is well adapted for long passages or similar situations.

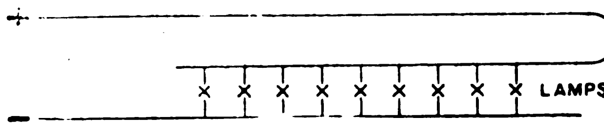


Fig. 124.

It will be noticed that by this method there is exactly the same length of lead to each lamp of the group.

The other and more generally adopted method, shown in Fig. 125, is known as the "ring-mains" method.

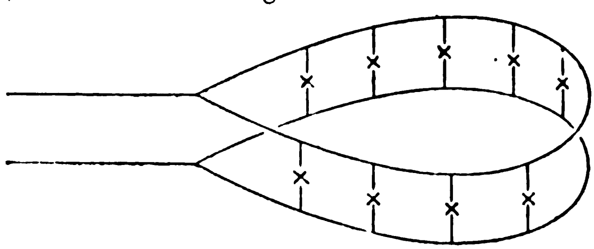


Fig. 125.

The above methods apply more particularly to the principal conductors in the building. As regards the lamp circuits especially, but also as regards the wiring as a whole, the arrangement now almost universally adopted for permanent work is that known as the distributing board system, in which the wiring is carried out as far as practicable from distributing centres. This is the system referred to under the heading "General Arrangement" in the rules of the I.E.E. (*vide* page 205) and some further brief detail on the subject is given below.

The Distributing Board System.

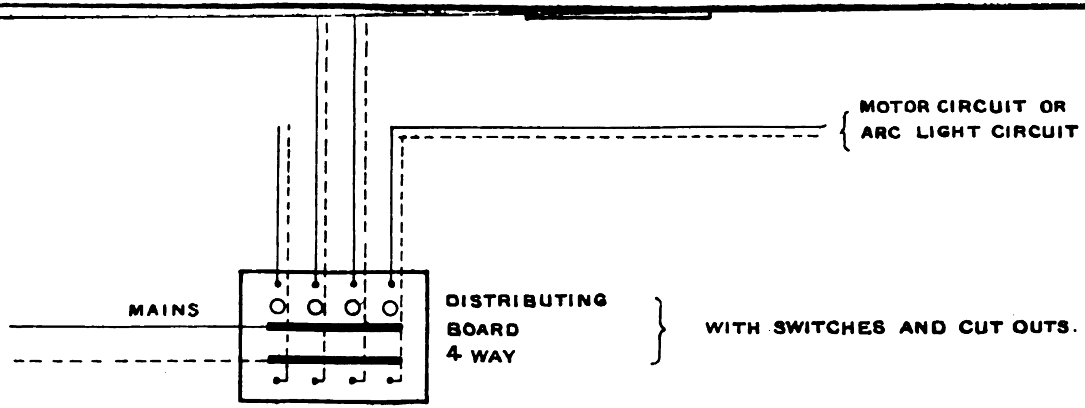
Plate XXV illustrates diagrammatically what is meant by wiring from distributing centres.

In a complete application of the distributing board method of supply, the conductors from each individual lamp would be run back from the lamp to a distributing board, and the lamp would be controlled and protected (by cut-outs) there.

It rarely happens that this completeness is carried out in practice. It generally entails a large expenditure on the wiring, and is usually unnecessary. When several lamps are required at one time there is no object in carrying out the above principle to the extent indicated, more especially so when, as is often the case, joints can be readily avoided by "looping."

One object to be attained is that the smallest cut-outs on any

To face page 196.



※ IT IS ASSUMED THAT CONTROL NEAR THE LAMPS THEMSELVES IS REQUIRED. THIS WOULD ORDINARILY BE THE CASE IN SUCH BUILDINGS AS DETACHED OFFICERS QUARTERS AND THE LIKE.

TYPE OF BOARD SUITABLE WHEN CONTROL AT OR NEAR THE LAMPS IS NOT REQUIRED. e.g. SOLDIERS BARRACK BLOCKS.

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circuit shall satisfactorily protect all conductors beyond it on the side furthest from the source of supply. If this is achieved there is no necessity to carry the same size of conductor from the cut-out right up to the lamp, nor is it necessary to insert a cut-out at every break of gauge.

Provided then that unnecessary joints are avoided, that all joints are accessible, and that safety requirements are satisfied, several lamps may be controlled by one switch and may be protected at one point. The extent to which this grouping is adopted will depend upon various factors, and no one rule suitable for universal application can be given.

The distributing boards (or boxes) would ordinarily be provided with a single pole cut-out on each side of each "branch" or "circuit" issuing from them, and a single pole switch on one (generally the positive) side of each circuit. Double pole cut-outs, *i.e.* two cut-outs mounted side by side on a common block, *e.g.* "casing cut-outs," are undesirable, such boards as are above referred to are, however, known as boards with "d.p. cut-outs," or with "one switch and two cut-outs per way," or as "d.p. boards."

The supply to the principal distributing board in a building would usually be controlled by a double-pole switch either forming part of the board or else provided separately.

Isolated cut-outs are not, as a rule, permissible, but the requirements of control may make it inconvenient to have to go to the nearest distributing board to turn a light on or off, and in such cases isolated switches become a necessity. Switches would then be omitted on the boards themselves.

Many different sizes of wire should, as previously stated, be avoided. Use the largest size the calculations give and carry right up to the fittings if possible.

The cut-outs and switches should be grouped as far as possible on distributing boards, from which each lamp or group of lamps should have its own pair of wires. It is recommended that single pole switches be used in conjunction with double pole fuzes. It will save much trouble if the wires are run on a definite system; if possible the leads and returns may be of different colours, otherwise it will be found useful to adopt some convention such as leads left or low, returns right or high according as the wires run vertically or horizontally.

The free use of labels and identification marks is very desirable everywhere, but nowhere more so than at the distributing switch-boards. These, as usually found, are only intelligible to the person who designed them or put them up; as in the Service the care of such things frequently changes hands, it cannot be too strongly insisted on that everything should be made as clear and intelligible as possible.

Fittings.

Lamps.

As before stated, lamps are either "brass collar" or "loop." Loop lamps are to be used where the lamp is subjected to vibration

or shock (such as gun fire) and in outside lighting where the plaster-of-paris* in the brass collar lamps deteriorates. Brass collar lamps are used elsewhere. Sometimes, however, passage lamps are made of "loop" pattern and barrack room lamps of "brass collar," in order to prevent unauthorised exchanges.

Detailed diagrams of lamps and their various fittings will be found in Plates XVII to XXI.

The lamps may, as shown, be fixed to brackets on the wall or suspended by cord grips from the ceiling. When cord grips are used, the wires should be first passed through the cord grip and then a small serving of twine or tape should be placed round the wire on the inside of the cord grip, large enough to prevent the served part passing through the hole in the cord grip. Enough slack should be left on the wires inside the holder to prevent any strain coming on the terminals of the holder.

Flexible wires should have their ends soldered up solid so as to prevent stray strands making accidental contact.

The standard size of hole in "shades" and such like fittings for incandescent lamps is $1\frac{1}{8}$-inch diameter.

Lamps of over 16-c.p. should not go into enclosing fitments such as "guards wire" or "pendant, ship pattern"; such lamps are not recommended for use at all if it can be avoided.

TESTS OF ELECTRIC LIGHT CIRCUITS.

Tests on Completion of Installation.

Insulation Resistance.

Method of taking test.

1. In addition to any tests which may be taken of the cables or fittings prior to erection, or during the progress of the work, a general insulation test will be taken, on completion, of the whole of the conductors and fittings connected to each main switchboard.

For the purpose of this test all fuses will be inserted and switches closed, but the holders will not be fitted with lamps. Arc lamps will be removed and tested separately.

The supply cables leading to the main switchboard will be disconnected.

Insulation required.

2. The insulation resistance of the whole of the conductors, switch and distributing boards, fittings, and accessories, from earth, and of the positive side of the installation from the negative side, must not be less than 10 megohms, divided by the maximum number of amperes required for the lamps and other appliances, on the basis of 4 watts per rated candle-power for incandescent lamps and allowing the nominal full load current for other appliances. Each branch or subdivision of the installation must also comply with this rule.

Testing of sections.

3. In each test if the insulation of the whole is below standard,

* Plaster-of-Paris is generally replaced by porcelain in modern lamps.

FITTINGS, INCANDESCENT LAMP, HOLDERS.

PLAIN, BAYONET JOINT. SHADE CARRIER, BAYONET JOINT.

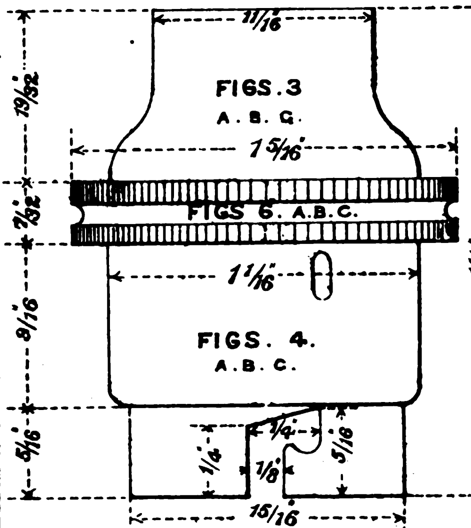


FIG 1.

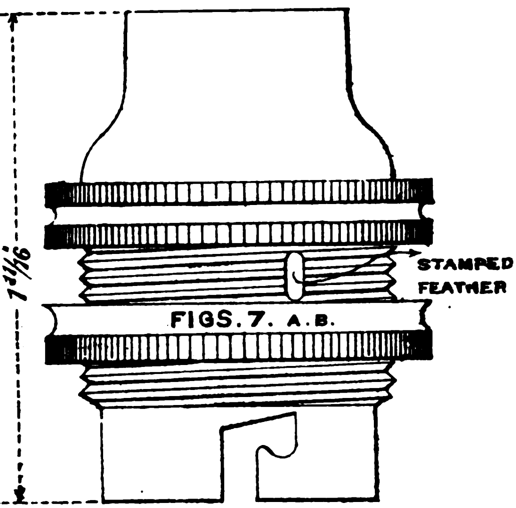
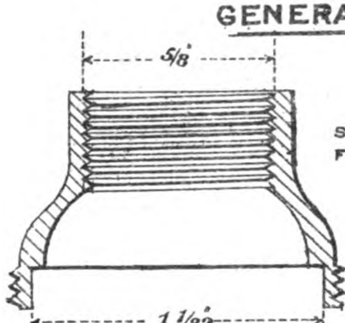


FIG. 2

GENERAL ELEVATION.



SECTION.

FIG. 3 A.

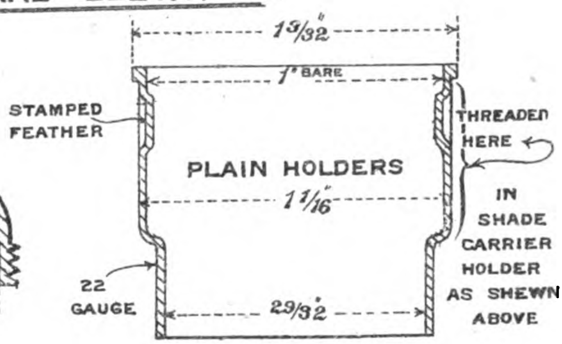


FIG. 4 A.

SECTION.

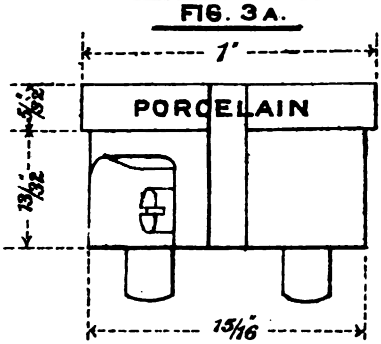


FIG. 5 A.

SIDE VIEW.

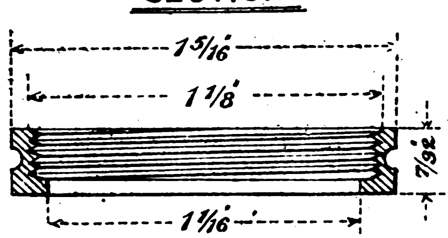


FIG. 6 A.

SECTION.

NOTE ABOVE THEADS ARE BRASS TUBE, 26 TO THE INCH.

SCALE. TWICE FULL SIZE.

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NOTE. PORCELAIN SAME FOR THIS AS FOR LOOP LAMPS.

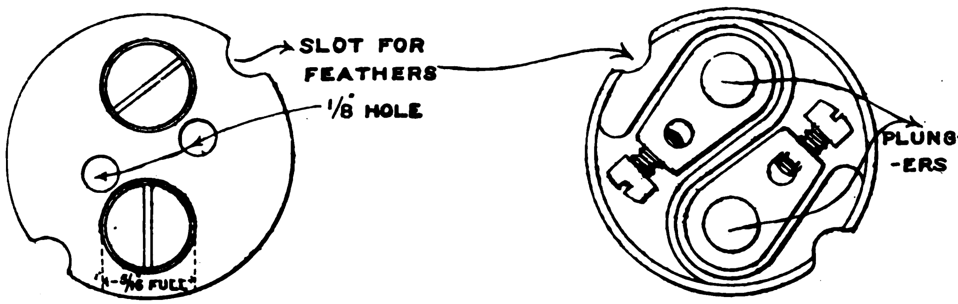
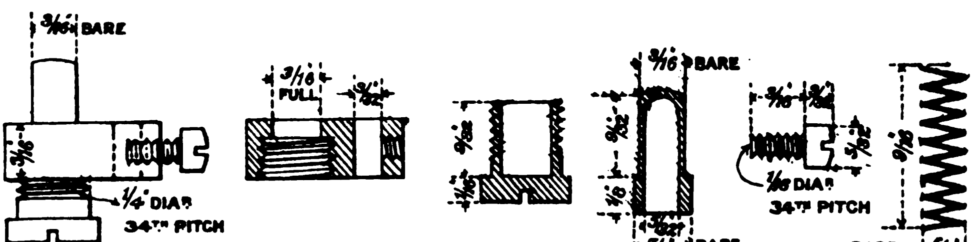


FIG. 5 B. TOP PLAN.

FIG. 5 C. INVERTED PLAN.

PORCELAIN BASE WITH PLUNGERS AND TERMINALS.



TERMINAL BLOCK SECTION.

PLUNGER.

PLUNGER SPRING

DETAILS OF PLUNGER AND TERMINAL BLOCK.

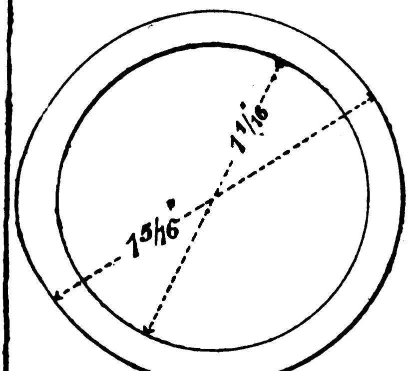


FIG. 7 A. TOP PLAN.

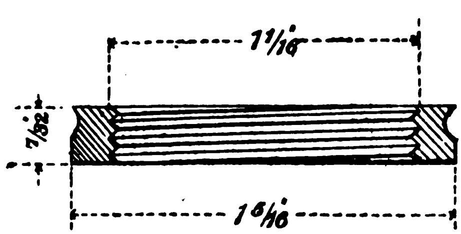


FIG. 7 B. SECTION.

FOR DETAILS OF CORD GRIP, SEE PLATE, HOLDERS FOR LOOP LAMPS; SAME CORD GRIP USED WITH HOLDERS FOR THE TWO CLASSES OF LAMP.

SCALE. TWICE FULL SIZE.

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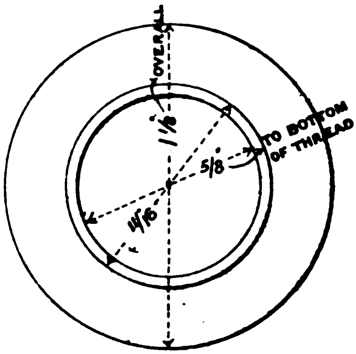

FIG. 3B.

TOP PLAN.

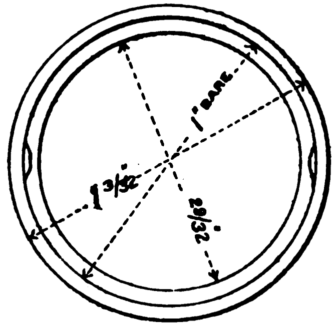

FIG. 4B.

TOP PLAN.

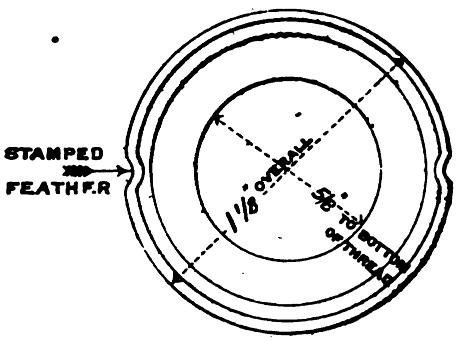

FIG. 3C.

INVERTED PLAN.

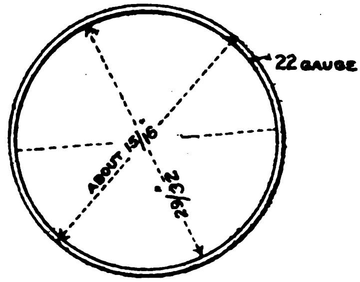

FIG. 4C.

INVERTED PLAN.

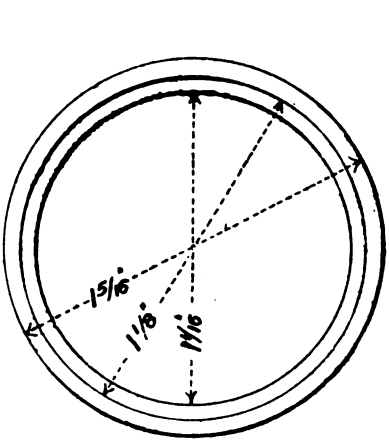

FIG. 6B.

TOP PLAN.

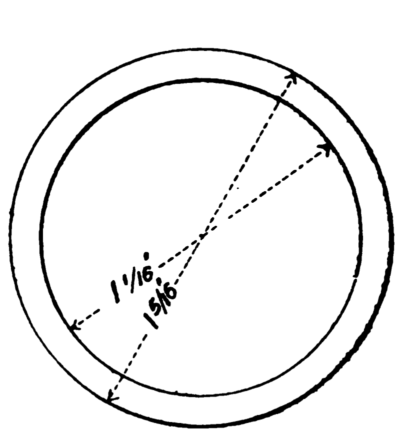

FIG. 6C.

INVERTED PLAN.

SCALE.—TWICE FULL SIZE.

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FITTINGS, INCANDESCENT LAMP HOLDERS.

PLAIN, LOOP.

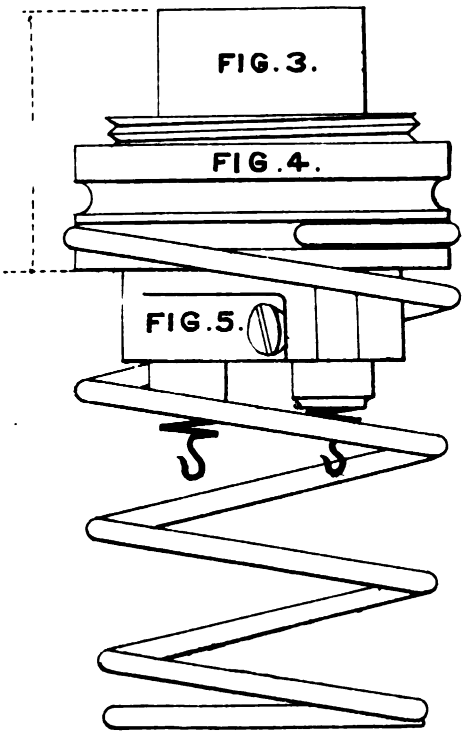


FIG. 1.

SHADE CARRIER, LOOP.

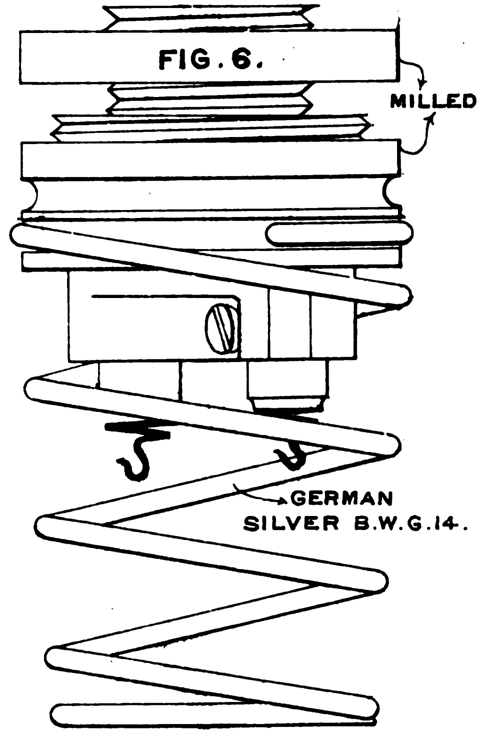
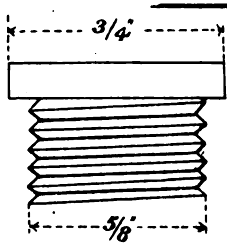
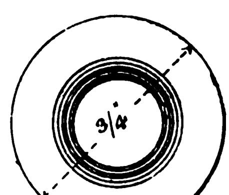


FIG. 2.

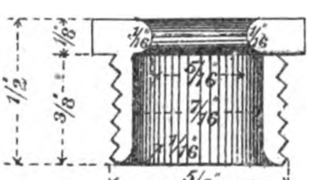
GENERAL ELEVATION.



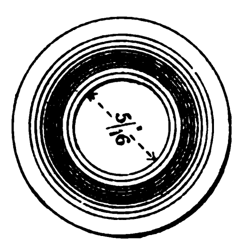
ELEVATION.



TOP PLAN.



SECTION.



INVERTED PLAN.

CORD GRIP, FOR LAMP HOLDERS OF THE BAYONET JOINT OR LOOP PATTERN, MADE ALL OF EBONITE.

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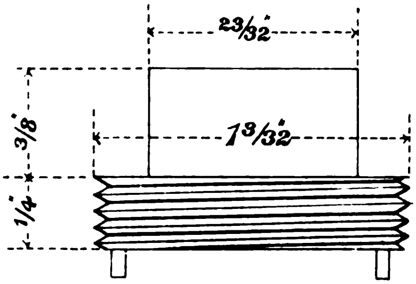

FIG. 3 A

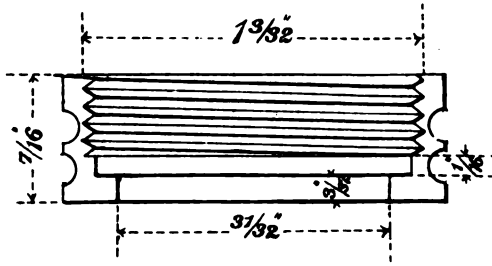

FIG 4 B.

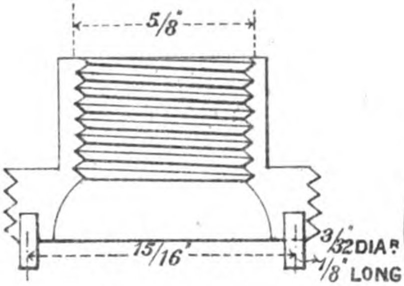

FIG. 3 B.

TOP PLAN.

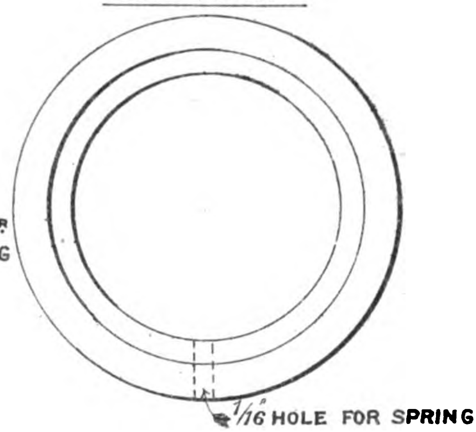

FIG. 4 C.

TOP PLAN.

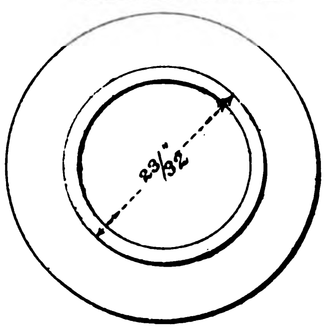

FIG. 3 C.

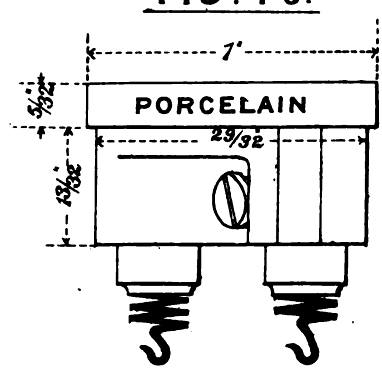

FIG 5 A.

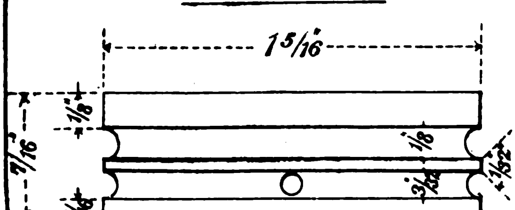

FIG. 4 A.

SCALE. TWICE FULL SIZE.

733. 6. 1900

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NOTE. PORCELAIN SAME FOR THIS AS FOR BAYONET JOINT LAMPS.

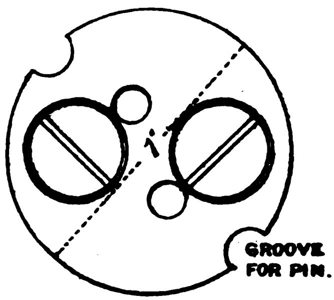


FIG. 5 B.

TOP PLAN.

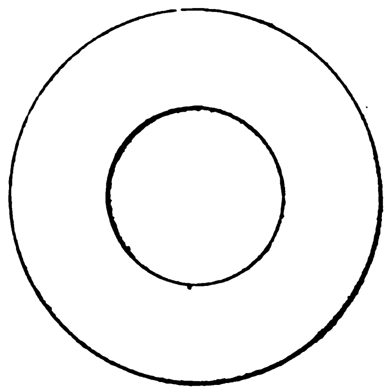


FIG. 6 A.

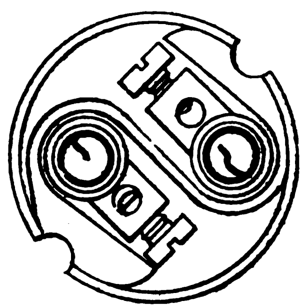


FIG. 5 C.

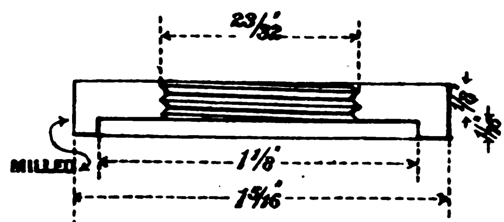
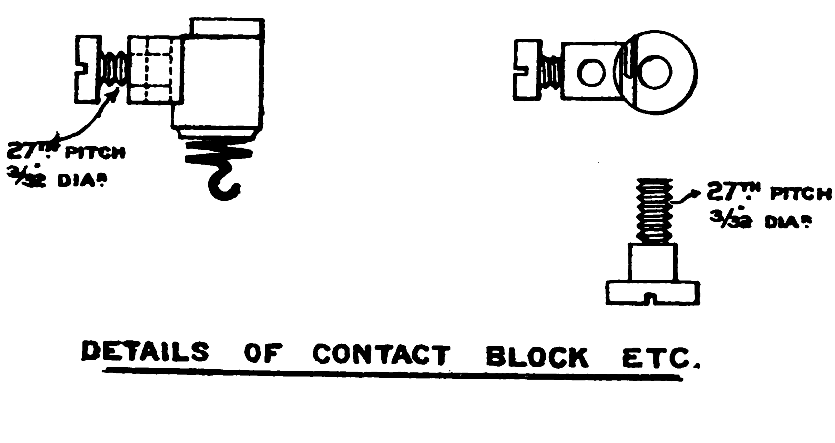


FIG. 6 B.



DETAILS OF CONTACT BLOCK ETC.

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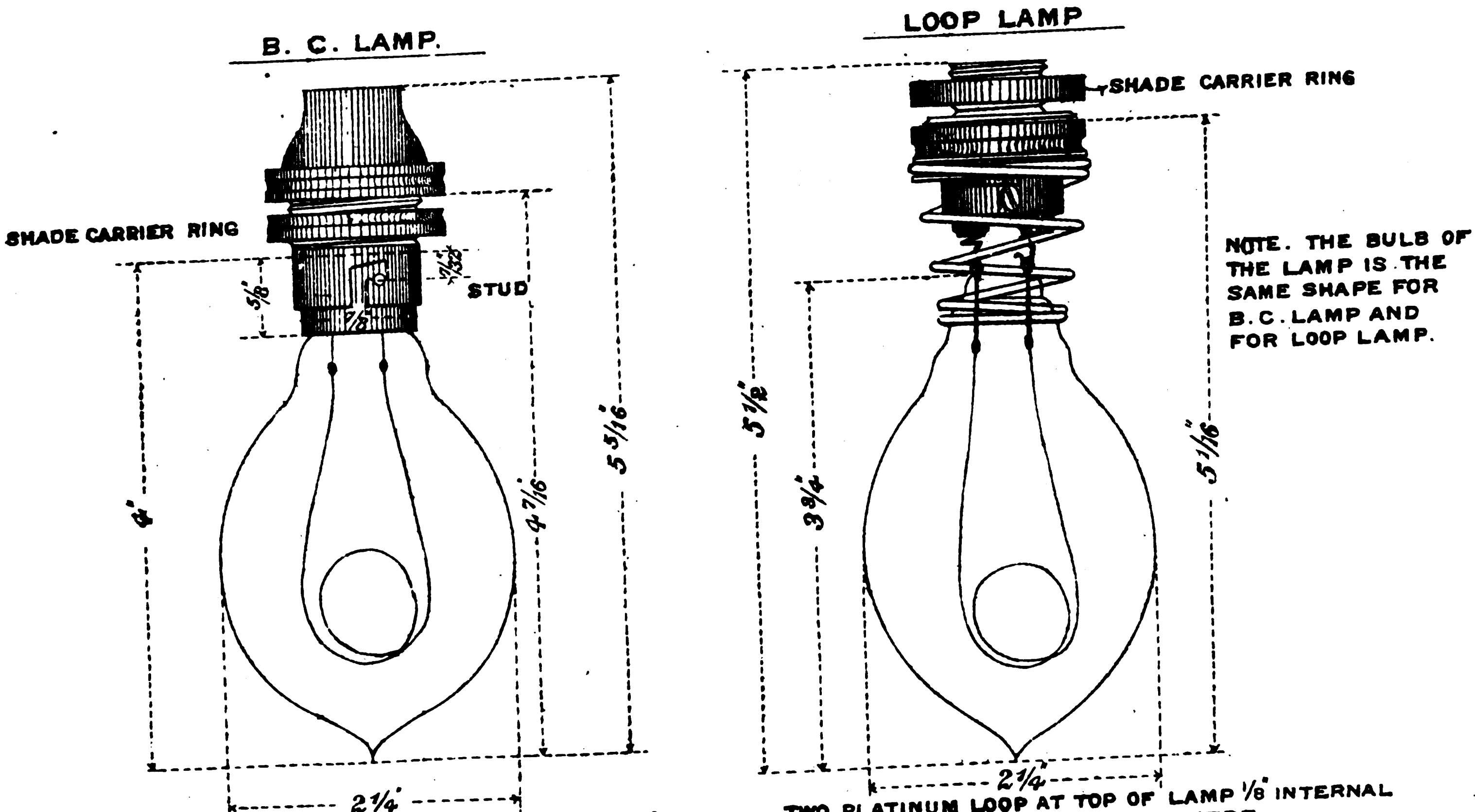
To face page 198.

PLATE XIX.

LAMPS, ELECTRIC, INCANDESCENT, FITTED IN HOLDERS.

SCALE. FULL SIZE.



TWO STUDS IN BRASS COLLAR OF LAMP DIAMETRICALLY OPPOSITE 5/64 DIA^{R} PROJECTING 3/32".

TWO PLATINUM LOOP AT TOP OF LAMP 1/8" INTERNAL DIA^{R} 7/16 APART CENTRE TO CENTRE.

733 . 6.1900.

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To face page 198.

PLATE XX.

FITTINGS, INCANDESCENT LAMP GUARDS, WIRE.

FULL SIZE.

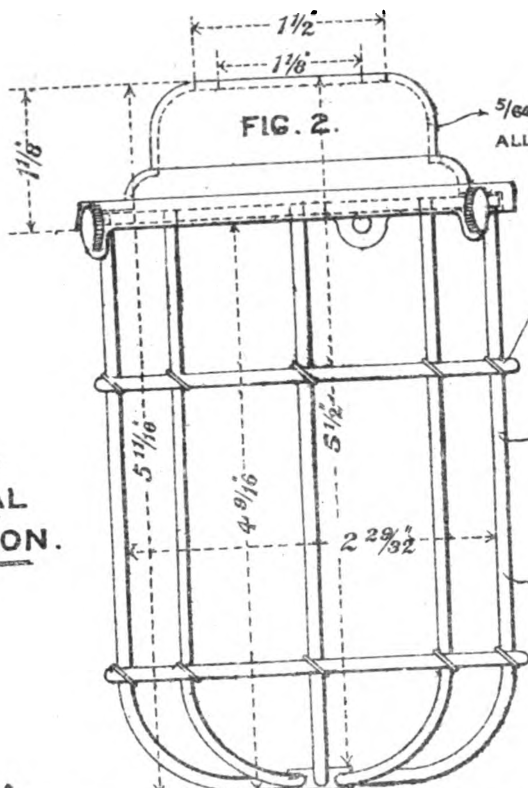


FIG. 1.
GENERAL
ELEVATION.

FIG. 2A.

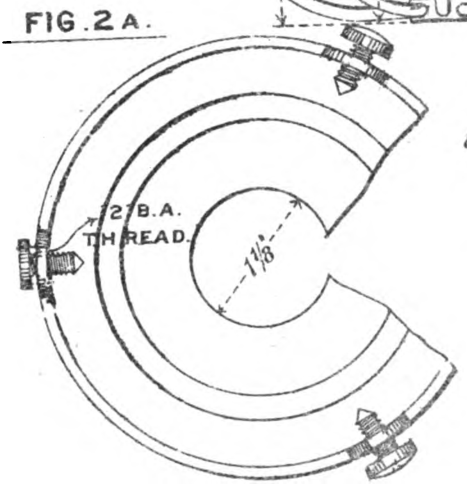
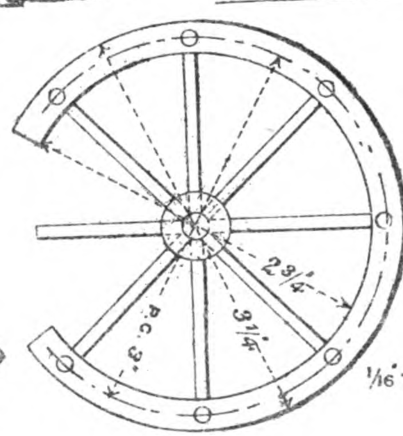


FIG. 3A



INVERTED PLAN.

BOTTOM PLAN.

723 6 1900

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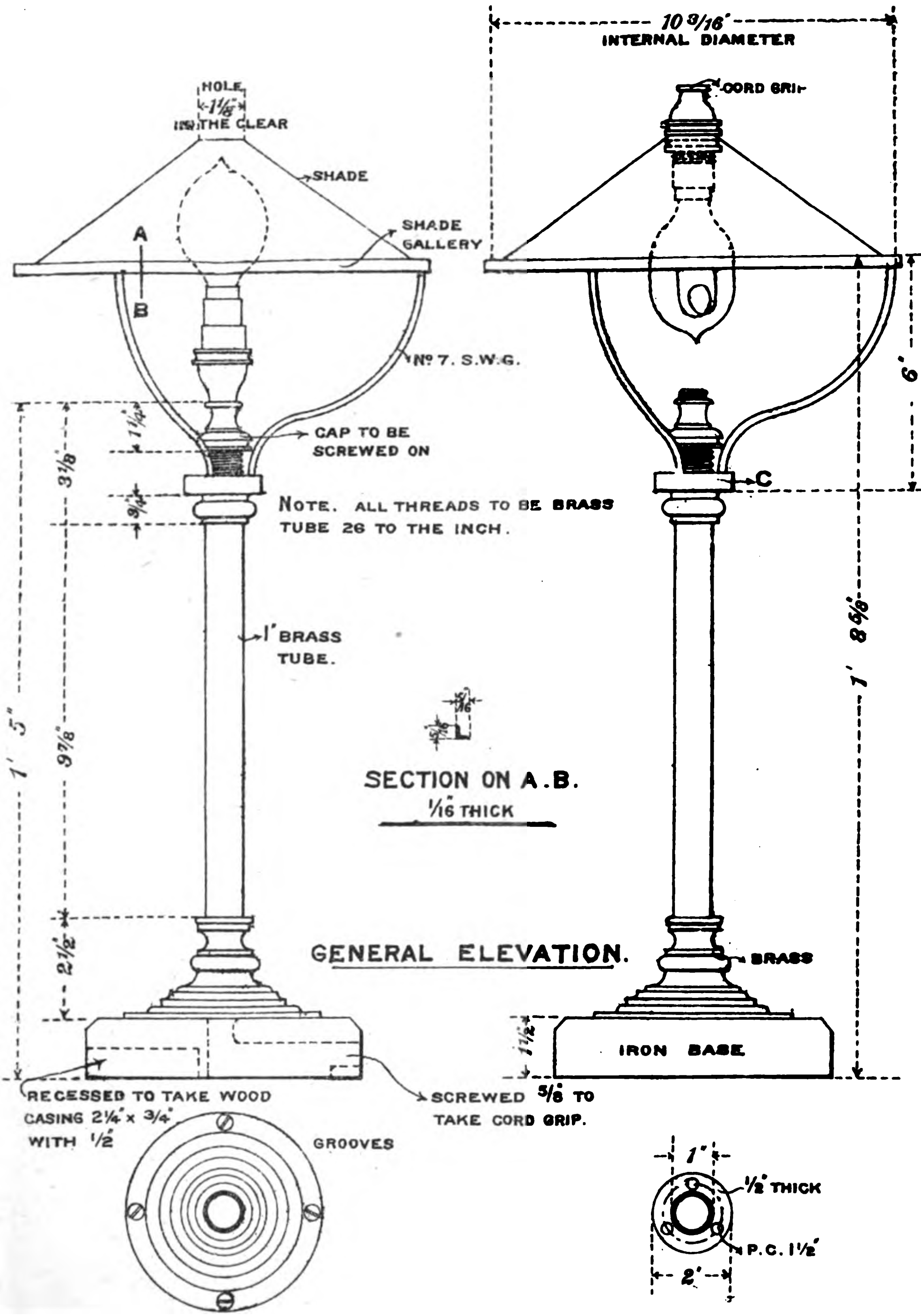
FITTINGS. INCANDESCENT LAMP STANDARDS.

SCALE. ONE THIRD FULL SIZE.



PLAN OF BASE.

TOP PLAN AT C.

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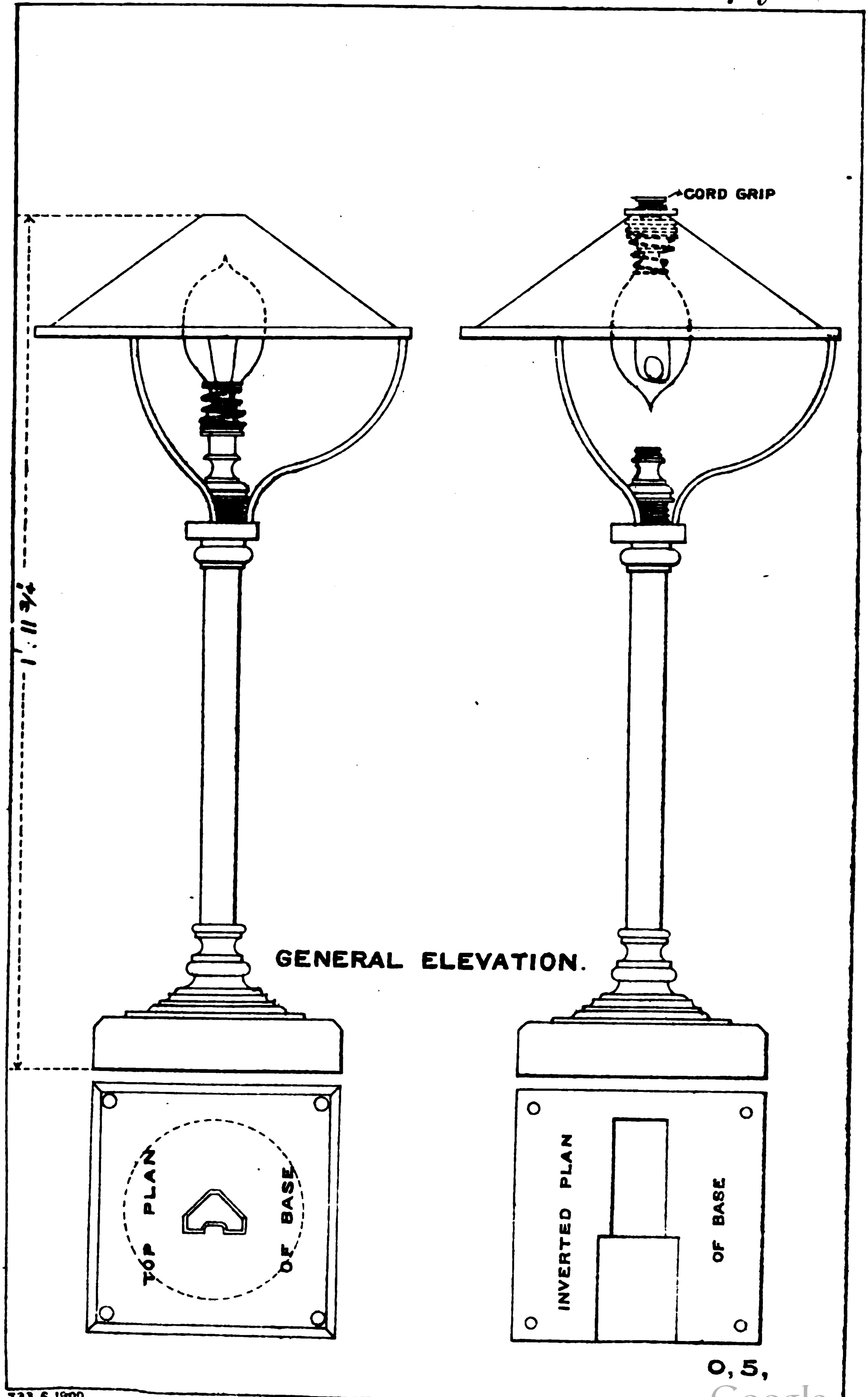

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the work should be divided up by the distributing switches and tested separately, in order to locate the faulty section.

4. If it is desired that each branch circuit connected to any main switchboard, or any group of circuits so connected, should be tested for insulation independently, the conductors under test must remain connected to the switchboard, those not under test being disconnected therefrom.

Disconnecting cables from switchboard.

5. When the supply of electricity is direct current, and obtained from a private installation, the tests will be taken through the cables leading from the dynamo terminals, instead of at the main switchboard.

Tests of cables from dynamo.

6. The insulation resistance of any motor or arc lamp measured between any portion of its electrical conductor and the frame or between any two electrically separated metal work on distributing boards or the like should be not less than one megohm.

Insulation resistance of arc lamps and motors.

7. If the foregoing tests are satisfactory, the incandescent lamps will be placed in their holders and the whole of the appliances for utilising the energy will be connected to the conductors if this has not been previously done, and the insulation resistance between the whole system and earth must not be less than 10 megohms divided by the maximum number of amperes required for the entire installation, calculated as already indicated.

8. For the purpose of measuring insulation resistance, a difference of potential not less than twice that normally existing in the circuits will be employed. The reading will be taken either by direct deflection of a suitable galvanometer or by an ohm-meter, after the pressure has been applied for one minute continuously. An ohm-meter reading to 50 megohms and a magneto-generator furnishing 500 volts have been adopted for this purpose. When a galvanometer is used, the necessary pressure is to be obtained by means of a battery. With an ohm-meter a battery, or a magneto-generator constructed to give the required difference of potential, will be employed. The negative pole of battery or generator is to be connected to the line.

Potential difference to be employed for tests.

Conductivity Resistance.

9. The conductivity resistance of the circuit will be tested as follows:—

Method of taking test.

> After the insulation tests have been completed and pronounced to be satisfactory, the current will be switched on, and the difference of potential at the lamp or other terminals compared with that at the point of supply. The potential difference at the lamp terminals must not be less than that due to the calculated resistance of the circuit, the current being either estimated in the manner already mentioned, or measured by ammeter.

10. In the event of any circuit not complying with the above, it must be disconnected and tested in sections for conductivity resistance by Wheatstone bridge method.

Localisation of defects in conductivity of conductor.

Measurement of conductivity by Wheatstone bridge.

11. Where practicable, the test specified in paragraph 9 may be taken by the Wheatstone bridge method if preferred.

Further Tests for Insulation.

12. After the installation has been at work for 15 days, an insulation test similar to that given in para. 7 above should be made. The general insulation of the system to earth will alone be taken unless it should prove to be faulty, in which case the circuits must be divided up by the distributing switches and tested separately.

Periodical Tests.

12. Periodical tests for conductivity and insulation resistance should be taken in the manner described in paragraphs 9 and 12.

These should be made twice annually, viz.: about October 1st and April 1st. The results obtained should be recorded.

Occasional Tests.

Insulation test.

13. Occasional tests for insulation should be made by means of a volt-meter, or high resistance detector galvanometer, with the pressure supplied to the mains.

The positive and negative conductors will be connected successively to one terminal of the instrument, the other terminal being connected to earth; should the insulation of either conductor be faulty, a deflection will be obtained when the conductor, which is clear of fault, is connected to the instrument.

The fault should be localised by testing the circuit in sections in a similar manner. When found and removed, the faulty circuit should be tested as specified in paragraph 11 before it is restored.

Probable causes of bad conductivity.

14 Defects in conductivity resistance may be due to bad joints, loose or dirty connections in fittings of holders, blown fuses or chemical or electrolytic action on conductors. The last-named defect may result from neglect to maintain the insulation resistance at a proper value.

These faults may manifest themselves either by total or partial extinction of lamps or by heating of fittings or conductors. All such faults must be localised and removed before the pressure is again applied to that part of the circuit.

Repairs not to be executed until pressure is removed from circuit.

15. No repairs or alterations are to be carried out until the pressure has been removed from the circuit by disconnecting both poles at the nearest double pole fuse or switch.

Extracts from R.E. Specification for incandescent lamps :—

Lamps.

1. The lamps to conform in all particulars to the pattern deposited in the Pattern Room, Inspection Division, R.E. Stores, Royal Dockyard, Woolwich, and this Specification, and to be of the best material and workmanship throughout. In case of any differences between the pattern and Specification, the Specification must be rigidly adhered to. The difference will be detailed on the pattern label as far as possible.

Construction.

2. The over-all dimensions of the lamps to conform approximately to those given in the attached drawing, unless any special dimensions are stipulated, in which case they must conform accurately thereto. **Dimensions over all.**

3. The terminals to be of such a description as may be ordered. Lamps having candle-powers higher than 50 will be required to be provided with lug terminals. **Terminals.**

4. Brass collar terminals to consist of a cylindrical brass tube, $\frac{7}{8}$ inch diameter external, and not less than No. 22 S.W.G. in thickness. The length of the collar to be not less than $\frac{5}{8}$ inch. The ends to be free from any burr. The collar to be cemented to the bulb by a hard non-porous insulating cement or other approved means. **Brass collar terminals.**

When cement is used, suitable keys for same to be provided by means of indentations in upper part of lamp bulb.

5. Two studs diametrically opposite to be provided. **Studs.**

The studs to be $\frac{5}{64}$ inch diameter, to project $\frac{3}{32}$ inch beyond surface of cap, and to be securely screwed, soldered or riveted into cap.

The centres of the studs to be situated $\frac{7}{32}$ inch from outer end.

6. The contact plates to be two in number, and securely fixed flush with end of cap. In no case is any portion of the surface to be below that of the cement. **Contact plates.**

Each plate to be $\frac{9}{16}$ inch long, and to be situated, with respect to the studs, so that the line through the centres of the plates shall be at right-angles to that through the studs.

The contact plates to be $\frac{7}{32}$ inch wide, and situated $\frac{7}{16}$ inch apart, centre to centre.

The platinum wire attached to the filament must be soldered to the long projection at underside of contact plates.

7. In the case of loop lamps, the loops are each to be formed of a strand of two or more platinum wires twisted together. The diameter of each platinum wire is not to be less than ·0148 inch (No. 28 S.W.G.). **Loop lamps.**

The internal diameter of each loop to be about $\frac{1}{8}$ inch. The loops to be of equal length and situated $\frac{1}{2}$ inch apart.

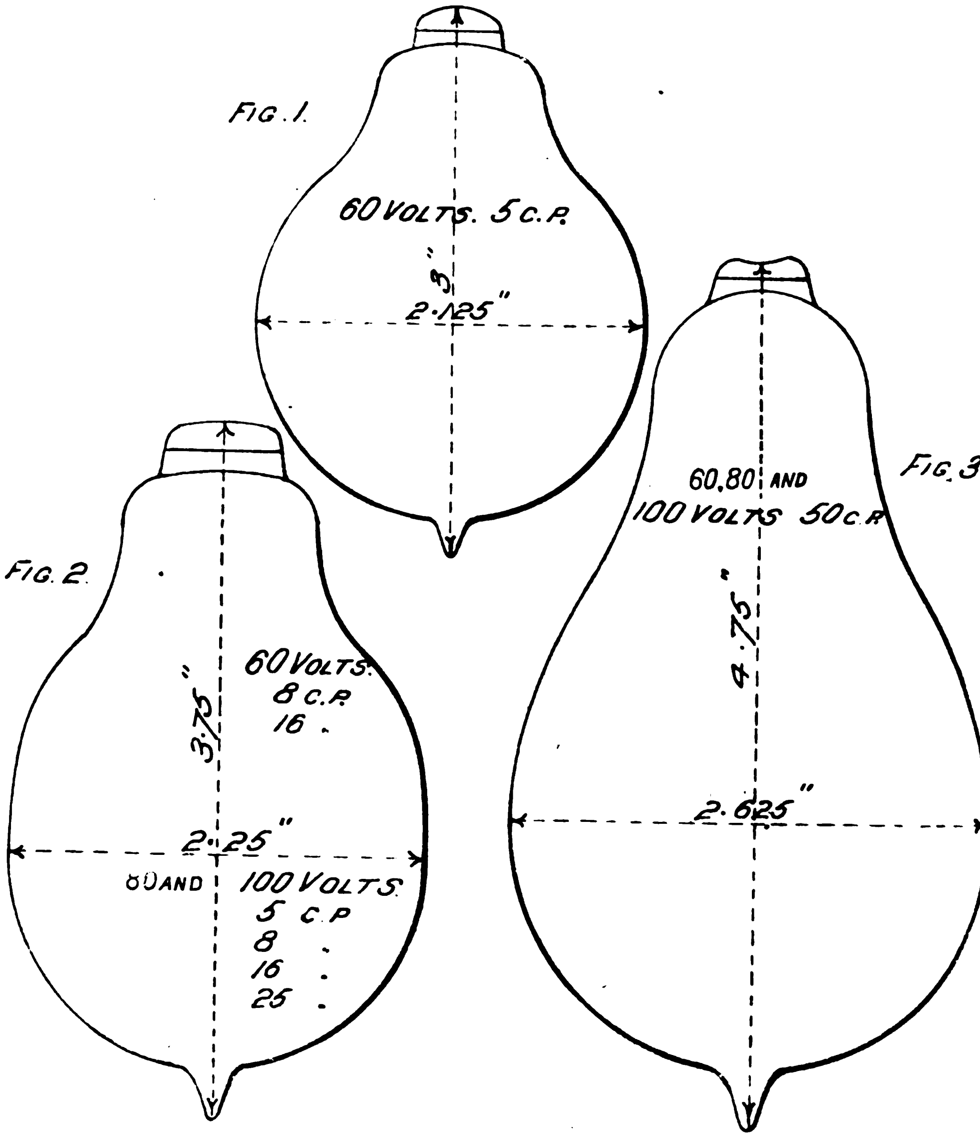

Fig. 126.

8. Other patterns of terminals, if ordered, must conform to samples which will be issued on application, or to samples submitted by manufacturers and approved.

9. The bulbs of clear lamps are to be perfectly transparent and colourless.

Coloured bulbs to be made of coloured glass. The obscuration of frosted lamps to be uniform at all parts of the bulb.

In no case are lamps coloured or obscured by means of varnish or lacquer to be supplied.

Filaments.

10. Each filament to be uniform in quality and diameter throughout its length, and to illuminate uniformly at all points.

The filaments to be securely attached to platinum connecting wires to the satisfaction of the Inspecting Officer.

The platinum wires used for this purpose to be of ample sectional area to the satisfaction of the Inspecting Officer.

11. In the case of loop lamps the outer ends to be bent over and fused into the glass, both wires of each loop passing into the bulb and being attached to the filament at their inner ends. **Platinum loops.**

Tests.

12. Lamps will be tested for—

Continuity.
Watt-consumption.
Candle-power.
Durability.
Vacuum.

13. The watt-consumption, total candle-power, and candle-power per watt will be measured with the normal potential difference for which the lamps are constructed. The results must fall within the limits shown in the attached table. **Watt-consumption and candle-power, Test No. I.**

14. For the purpose of this test a number not greater than 5 per cent. of the total number supplied with a minimum of 10 lamps shall suffice, unless the Inspecting Officer shall decide to test a larger percentage. **Percentage to be tested for candle-power and efficiency.**

15. Any lamps falling outside the limits will be rejected, and should 5 per cent. of those tested, with a minimum of two lamps, fall outside these limits, the whole supply may be rejected. **Limits of departure from standard.**

16. After the lamps have been tested for candle-power and watt-consumption under normal conditions, the pressure at the lamp terminals will be gradually raised until it reaches, in 2½ minutes, the pressure stated in column entitled Test No. II of the table (para. 20). This pressure reached, the current will be at once turned off. **Durability, Test No. II.**

17. The lamps will then be re-tested as described in para 13. The limits allowable for each kind of lamp as regards candle-power, and the maximum watts per candle-power, are set forth in the attached table (para. 20) in columns entitled Test No. III. **Test No. III.**

18. In lieu of Tests II and III a proportion of the lamps, not exceeding one-third of the whole number selected for tests mentioned in paras. 16 and 17, will be raised gradually in three minutes to the pressure stated in the last column of the table. The lamp under test must not fail in any way under these conditions while the pressure is being raised. **Test No. IV.**

Number to tested for durability.

19. The number of lamps selected for the tests described in paras. 16 and 17 will be as follows:—

Delivery of	3,000 or over ...	...	1 per cent.
„	1,000 to 3,000 ...	...	2 „
„	less than 1,000...	...	3 „

20. TABLE of Tests.

Terminals.	Standard volts.	Standard C. P.	Test No. I. C. P. Max.	Test No. I. C. P. Min.	Test No. I. Max. Watts per Candle.	Test No. II. Pressure raised in 2½ mins.	Test No. III. C. P. Max.	Test No. III. C. P. Min.	Test No. III. Max. Watts per Candle.	Test No. IV. Pressure raised in 3 mins.
						Rise % volts.				Rise % volts.
		5	5·5	4·5	4·5		6·0	4·0	4·7	
		8	8·5	7·5	3·9		8·8	7·2	4·1	
B.C.	100	16	17	15	3·75		17·6	14·4	4·0	
or	to	25	26·5	23·5	3·5	70	27·5	22·5	3·75	110
Loop.	115	32	34	30	3·4		35	29	3·65	
		50	53	47	3·3		...	...	...	
Lug.	...	100	106	94	2·9		...	...	...	
		5	5·5	4·5	4·3		6	5	4·5	
		8	8·5	7·5	3·9		8·8	7·2	4·1	
B.C.		16	17	15	3·7		17·6	14·4	4·0	
or	80	25	26·5	23·5	3·5	70	27·5	22·5	3·75	110
Loop.		32	34	30	3·4		35	29	3·65	
		50	53	47	3·3		...	...	...	
Lug.	...	100	106	94	2·9		...	...	...	
		5	5·5	4·5	3·[illegible]		6·0	4·0	4·1	
		8	8·5	7·5	3·75		8·8	7·2	4·0	
B.C.	50	16	17	15	3·4		17·6	14·4	3·65	
or	to	25	26·5	23·5	3·3	70	27·5	22·5	3·75	110
Loop.	60	32	34	30	3·2		35	29	3·65	
		50	53	47	3·1		...	...	...	
Lug.	...	100	106	94	2·9		...	...	...	

Vacuum.

21. The exhaustion of each bulb must be as perfect as possible, and will be tested by means of an induction coil suitable for giving a spark ⅜ inch long.

When the lamp is connected between the high tension terminals of the coil, and the spark points set so that no spark passes, no glow must appear in the space between the filament and the walls of the lamp. Any glow which may be seen must only be on the inside surface of the glass.

Miscellaneous.

Candle-power of frosted lamps.

22. Frosted lamps must give their nominal candle-power when tested on a photometer, and will be required to pass the tests laid down in paras. 12 to 19, except that they may absorb 15 per cent. more watts per candle-power measured than shown in table, para. 20.

Candle-power of coloured lamps.

23. Lamps having coloured bulbs are to be fitted with filaments similar to those used for clear lamps of some nominal candle-power. They will not be tested photometrically, but must in other respects conform to the Specification. The colour of the

glass to be good, but not so dark as to render the lamp unsuitable as a source of light.

24. The standard of light will be the British standard candle, and the source of light a Dibdin Pentane Lamp, giving a light of 10 standard candles. **Photometric standard.**

25. All lamps supplied are to be indelibly and distinctly marked on the upper part of the bulb with the following information, viz.:— **Marking.**

Candle-power.
Voltage.
Name of maker.

*General Rules for Wiring for the Supply of Electrical Energy.

These rules embody the chief precautions and requirements which the Institution considers necessary to secure satisfactory results.

They have been drawn up to meet the ordinary cases of dwelling-houses, offices, or business premises in which it is desired to lay the conductors, and fix the fittings and appliances necessary for utilising electrical energy either for lighting, for heating, for motive power, or for other purposes.

They are arranged in such a form that they may be used as a specification of requirements and precautions which must be strictly enforced if a user of electrical energy wishes to have his houses or premises supplied in such a manner that he may be as free as possible from risk of fire, of extinction, failure of supply, or danger to person, and at the same time have his work carried out with due regard for economy both in first cost and in after cost of maintenance.

The rules are framed to meet all ordinary cases, but they are not intended to take the place of detailed specifications drawn up by consulting engineers to meet individual requirements.

They are confined to a statement of well-ascertained requirements, and do not recommend any special system or form of apparatus by which these may be best fulfilled.

For convenience the rules are grouped as below :—

Conductors.

1. Conductivity and size.
2. Insulation.
3. Joints.
4. General arrangement.
5. Precautions where they pass through walls or partitions.
6. „ at points of connection.

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* **The rules are printed by permission of the Institution of Electrical Engineers.**

Fittings.	7.	Precautions as to switches, fuses, and other appliances.
	8.	Switches.
	9.	Switch-boards.
	10.	Fuse boxes and fuses.
Generating and Utilising Appliances.	11.	Dynamos and motors.
	12.	Accumulators or other batteries.
	13.	Transformers.
	14.	Arc lamps.
Testing.	15.	Testing the whole and parts.

Conductors—Conductivity and Size.

1. They should be of high-conductivity copper not less than 100 per cent. conductivity, and where sulphur or other substance liable to attack bare copper is contained in the insulation, they should be tinned with pure tin.

Note.—The standard of conductivity here referred to is, that the resistance of a copper wire weighing 100 grains, 100 inches long, should be 0·1516 ohm at 60° Fahr.

Sectional area.

Their sectional area should be proportional to the heating effect of the current required for the maximum number of lamps, or other current-using apparatus, that can be used simultaneously on the circuit; but in no case should the sectional area of any conductor be less than that of a No. 18 S.W.G. wire. All conductors having a sectional area larger than that of a No. 14 S.W.G. wire should be stranded.

Temperature limits.

They should be of such size that when the maximum current is passing continuously through them their temperature shall not exceed 130° Fahr. It will, however, generally be found that if the conductors are worked up to a density of current corresponding to this increase of temperature, the resulting fall of potential or drop in volts will be inconvenient and uneconomical. It is imperative that this temperature of 130° Fahr. should never be exceeded, and therefore it is necessary to take into account the maximum temperature to which they may be subjected, independently of electric heating, in each particular locality, and the greatest increment above this temperature should not be more than will raise them to a temperature of 130° Fahr.

If the maximum temperature of the British Islands be taken as 100° Fahr., then the increment due to electric heating must not exceed 30° Fahr., that is to say, the size of the wires should be such that, when carrying the maximum current continuously for many hours, the temperature does not rise more than 30° Fahr. above the temperature, for the time being, of the place in which they are situated. In specially hot places the wires should be so large that the electric heating should be almost nil, and the wires should be specially insulated with insulating material which does not deteriorate at the highest temperature to which it will be subjected.

The table appended shows size of conductors which will safely carry currents up to 740 amperes, and the length in yards of single conductor in circuit for each volt of fall of potential when the maximum current is in use.

Insulation.

2. Insulated conductors may be broadly classed under two heads— **Insulation.**

A. Those insulated with a material as a dielectric which is itself so impervious to moisture that it only needs further protection from mechanical injury or from vermin.

B. Those insulated with a material as a dielectric which, in order to preserve its insulation qualities, must be kept perfectly dry, and therefore needs to be encased in a waterproof tube or envelope, generally of soft metal, such as lead, which is drawn closely over the dielectric.

When class A is used the dielectric must be perfectly damp-proof, and not in any case less in thickness, measured radially, than 30 mils plus $\frac{1}{10}$th of the diameter of the conductor; it should not soften at a lower temperature than 170° Fahr.; the minimum insulation of a test piece cut from it should be that given in column 7 of the table, the test being made at 60° Fahr. after one minute's electrification, and after the test piece has been immersed in water for 24 hours.

When class B is used the same conditions as to minimum thickness and softening temperature of the dielectric should be enforced as in class A; its covering should be such that a test piece cut from the conductor and immersed in water will not break down when an alternating pressure of 2,500 volts having a frequency of from 40 to 100 periods per second is applied for 10 minutes between the conductor and the water, the test piece previous to immersion having been bent six times (three times in one direction and three times in the opposite direction) round a smooth cylindrical surface not more than 12 times the diameter of the conductor, measured outside the dielectric. The coil from which the test piece was cut should be tested in a similar manner to Class A, but the minimum insulation resistance should be that given in the table, column 8.

Conductors of class A must be protected from mechanical injury by being covered with stout braid or taping, prepared so as to resist moisture, and must be further protected by casing, or by being drawn into pipes or conduits.

In the case of conductors insulated as in class B great care must be taken to protect exposed ends of conductors where they enter the terminals of switches, fuses, and other appliances, from the possible access of moisture which might creep along the insulating material within the waterproof covering.

Concentric conductors should in all respects conform to the requirements herein laid down for single conductors; the insula- **Concentric conductors.**

tion resistance of the outer dielectric should be that given in the table for single conductors having the same diameter as the outer conductor. The insulation resistance of the dielectric separating the two conductors should be twice that of the outer dielectric.

The bending test of concentric conductors, class B, should be made round a cylinder 12 times the diameter of the outer dielectric.

Flexible cord conductors. Flexible cord conductors—*i.e.* those made up of a number of wires not larger than No. 29 S.W.G., which are then insulated (in many cases two such conductors are twisted together so as to form a double conductor)—should only be used for attachment to portable appliances, or for the wiring of fittings; the insulating material used as the dielectric should be either pure rubber or vulcanised rubber of the best quality. If pure rubber be used, it should be laid on in two laps, care being taken that these should lap-joint. The radial thickness of the dielectric should never be less than 16 mils for pressures up to 125, or 20 mils for pressures up to 250 volts. Each coil should bear a certificate that a piece one yard in length cut from it has withstood for five minutes an alternating pressure of 1,000 volts having a frequency of from 40 to 100 periods per second applied between the two conductors twisted together, the piece being subjected during the test to the vapour arising from a pan of boiling water placed at a distance not exceeding 3 feet, and immediately below it.

Joints.

Soldering fluids prohibited. 3. All joints in conductors must be mechanically and electrically perfect, to prevent heat being generated at these points. The use of soldering fluids containing hydrochloric acid, sal ammoniac, or other corrosive substances, should be absolutely forbidden. The insulation of all joints in insulated conductors should be most carefully attended to, the object being to make the insulation of the joints as nearly as possible equal to the insulation of the remainder of the conductor.

Jointing precautions. In jointing rubber-insulated cable, care should be taken that the braiding or taping is carefully removed without damage to the india-rubber, which latter should be laid bare, and tapered for sufficient length to ensure a water-tight union with the insulating substance used as a covering. It should be remembered when arranging for any system of wiring that joints constitute a source of weakness, and they should, therefore, be avoided as far as possible.

General Arrangement.

Distributing centres. 4. The arrangement of conductors should be carried out as far as possible from distributing centres, the cable conveying the current to them being free from joints; from these centres of distribution the use of small circuits carrying up to 5 amperes, and also free from joints, except at the branches and connections

to switches and other appliances, is recommended, in order that the fuses at these centres of distribution may amply protect every conductor beyond them, even if only a "flexible" for a single lamp.

This will ensure safety, although the ideal system is to carry a conductor from each point of use back to the distributing centre without joint or tapping.

The use of a draw-in system in which both conductors are drawn into one strong incombustible tube or chamber, or their equivalent, is preferable to wood casing with spaced conductors, as safety is better obtained by the use of suitable insulation of the wires themselves than by trusting to the wood casing, or to the spacing for insulating purposes. The composition of the tubing or conduit used must depend on the character of the structure in which it is embedded; tubes or conduits which minimise condensation or sweating are to be preferred. When tubes are used no elbows should be employed, but corners should be turned either by means of slow bends or by the fixing of a suitable box. **Draw-in systems.**

Conductors spaced and separated away from the walls should not be permitted unless they are mechanically protected throughout their entire length. Where the distribution is effected by circuits not carrying more than 5 amperes, conductors of the same polarity may be "bunched" together, providing a double-pole fuse, arranged to sever the circuit before any perceptible rise of temperature can take place, is inserted at the point of distribution; conductors of opposite polarity may also be "bunched," provided that they are placed in an incombustible tube or conduit. **Conductors spaced from walls.**

Precautions where Conductors pass through Walls or Partitions.

5. Cables or wires passing through walls require additional protection, such as a porcelain or other tube which can be filled up with sand or other chemically inert incombustible material, so as to prevent the spread of fire through these openings. Wherever conductors cannot be in sight they should be made as accessible as possible; and it is recommended that wires which must be buried within walls should not be fixed, but drawn into channels previously prepared for them, and they should preferably not be drawn in until any dampness which may exist in these channels has dried out of them. **Porcelain tubes in walls.** **Conductors drawn into channels.**

Conductors should not be placed near gas pipes. **Gas pipes.**

Precautions at Points of Connection.

6. Wherever conductors are connected on to switches, fuses, or other appliances, great care must be taken that the whole of the separate wires forming the stranded or flexible conductor are neatly twisted together and clamped into the terminal, so that no loose wire or strand can project; the insulating material or dielectric should only be bared back sufficiently to allow of the **Jointing on to switches.**

conductor entering into the terminals properly, and the ends of the insulation should be thoroughly sealed, to prevent moisture creeping along the copper beneath the insulation.

The braiding, lead, or other non or semi-insulating material, should be cut back for a distance of not less than ¾ inch from the end of the insulating material.

Precautions as to Switches, Fuses, Connectors, and other Appliances.

Bases to switches, &c.

7. These should be mounted on bases made of porcelain or other non-combustible material. If any difficulty arises through damp, this may be overcome by inserting a second base or backing of specially prepared material.

Damp places, &c.

In excessively damp places, such as cellars, all fittings attached to walls should, as far as possible, be dispensed with, the wires being carried direct from the distributing board to the lamps.

Frames for resistances.

Resistance coils should in all cases be carried on frames or supports made of incombustible material, and preferably should be enclosed in metal cases, to prevent accidental derangement.

Wiring of fittings.

Whenever fittings, such as brackets, electroliers, or standards, require to have the conductors threaded through tubes or channels formed in the metal work, these should be designed so as to avoid sharp angles or rough projecting edges which would be liable to strip or cut or damage the insulating material in the act of drawing in the conductors, or in fastening them to the outside in the case of adapted fittings. The use of combined gas and electric fittings should not be permitted; where gas fittings are adapted, they should be insulated from the gas pipe.

Adapting gas fittings.

Jointless conductors.

Where possible, the conductor should be carried without joint through the fitting to the lamps; but where connections at the back are unavoidable, special care must be taken to make this joint equal in quality, as regards conductivity and insulation, to the rest of the work.

Switches

8. Every switch, whether fixed separately or combined with lamp holders or fittings, should be constructed to comply with the following requirements:—

(*a*) That no overheating can take place at the point of contact or elsewhere.
(*b*) That when being switched off it is impossible for a permanent arc to be formed.
(*c*) That it cannot be left in an intermediate position between on and off.
(*d*) The base should be of incombustible material.
(*e*) The cover should also be of incombustible material, and should preferably be either made of or lined with non-conducting material.
(*f*) Covers of all switches should be kept clear of all the internal mechanism.

(*g*) The handles of all switches should be efficiently insulated from the circuit.

(*h*) In order to ascertain that switches comply with the above requirements, samples should be selected from each pattern and size used, and should be tested at an E.M.F. and current 50 per cent. in excess of that which will be used on the circuits for which they are intended.

Main switches should be placed close to the generators if the supply is generated within the building, or at the transformer if transformed within the building, or at the point of entrance of the conductors into any building supplied from an external source.

When all three wires of a three-wire system are brought into a house, the member of the switch connected to the middle wire must not make contact later, or break contact sooner, than the other two members; preferably the middle member should make contact *sooner* and break contact *later* than the two outer members. Single-pole switches should not be on the middle wire of a three-wire system. In a five-wire system the same principles will apply.

Switch-Boards.

9. Whenever main or centres of distribution switch-boards are provided, these should be constructed of incombustible material, preferably with front connections, with circuits arranged as far as possible to form their own diagram of connections, and so labelled that they may be easily identified. Where back connections are permitted, they should be carefully soldered. Exposed metal work of different polarity on switch-boards should be well separated, and preferably mounted on separate bases.

Diagram of connections.

Exposed metal work

Fuse Boxes and Fuses.

10. Branches from all circuits should have fuse boxes made of porcelain or other incombustible material on both poles, and the fuses in these fuse boxes, if on the same base, should be in separate compartments. Where the tree, or tapered system of wiring is allowed, fuses should be introduced at such intervals that each fuse protects the smallest branch between it and the next fuse; or, if there is no other fuse, then it must protect right up to the end of the circuit. If the above precautions are taken, it is not necessary to protect the ceiling roses which support flexible pendants, by fuses at the ceiling point of junction.

Fuses on both poles

Fuses on tapered mains.

Fuses in ceiling roses

Whenever circuits not exceeding 5 amperes have fuses in each pole at the distributing point, fuses in the connectors (see Section 7) are not necessary; should the current, however, exceed 5 amperes up to 125 volts, or 3 amperes up to 250 volts, all portable fittings requiring flexible cords, or adapted fittings wired with flexible cords, must be protected with a fuse at the point of junction with the circuit.

Fuses in portable fittings.

Any fitting containing many lights and wired with flexible cord

should be supplied by conductors carried back to the distributing centre.

Where one of the conductors is connected to earth, all switches and fuses which will be single-pole should be arranged on the insulated side of the system.

No fuses or switches should be placed in or at any point of the earthed conductor.

Standard types of fuses should be so designed as to avoid the risk of inserting fuses intended for large circuits into the fuse carriers of small circuits, and *vice versâ*.

Ventilation of fuse boxes. The covers of all fuse boxes—whether these be separate or grouped on switch-boards—should be efficiently ventilated, so as to avoid risk of fracture by the sudden expansion of the air within them at the time the fuse melts, the covers being arranged to catch and retain the fused metal.

All connectors should be capable of withstanding a test at an E.M.F. and current 50 per cent. in excess of that for which they are intended. If used in damp places special precautions must be adopted to exclude moisture.

Connectors in floors. In cases where the fixed part of the connector is attached to a floor it must be so arranged that no dust or water can accumulate in the cavity, and should have all contacts well below the floor level, to prevent any possibility of danger from contact with the carpets.

Concentric connectors. When concentric connectors are used they must be constructed so that they cannot be readily short-circuited by a piece of metal, such as a pin or a metal pencil-case. Clearances should be such that an arc cannot be started if the connector is pulled out at the time that the current is flowing. The insulation used between opposite poles should be such that it will not readily break or chip.

Dynamos and Motors.

Spacing of dynamos, &c., away from woodwork. 11. Dynamos and motors should be protected from damp and dust, and should be so placed that no woodwork or inflammable material is within a distance of 12 inches from them measured horizontally, or within 4 feet from them measured vertically above them; and the same precautions must be adopted in placing and fixing the starting switches or regulating resistances used in connection with any of these appliances.

Spacing of resistance coils. The coils of these resistances must be so designed that in no case do they heat above 212° Fahr. even if left continuously in use; and the coils must be protected by suitable metal casing or guards, which must not interfere with free circulation of the air round the coils.

Earthing the frames. The frames of dynamos or motors employing an E.M.F. of 250 volts or upwards should be connected to earth.

Continuous-current transformers are to be classed with dynamos and motors.

Accumulators or other Batteries.

12. Both accumulators and primary batteries should be placed and used under the same precautions as above described for

dynamos and motors, and the room in which they are placed should be well ventilated. The accumulators and batteries should themselves be well insulated from the earth, and should be protected by fuses at both poles, and at all points of connection between the circuit and the regulating cells.

Transformers.

13. When these are used to transform either direct or alternating currents of high E.M.F. down to the E.M.F. allowed by the Board of Trade on the consumer's premises, they, together with their switches and fuse boxes, must be placed in a fire- and water-proof structure, preferably outside the building for which they are required, and their frames must be connected to earth.

No part of such apparatus should be accessible except to the person in charge of them. In all cases conductors conveying currents of high E.M.F. inside a building must be specially insulated and encased in a fire-proof conduit. Under no circumstances should transformers be allowed to heat under normal conditions of load to a temperature of 150° Fahr. Transformers should be so protected by suitable apparatus that a leak between the primary and secondary coils raising the pressure to 400 volts above that of the earth should cut the transformer out of circuit.

Low-pressure transformers

Low-pressure alternating transformers or choking coils may be placed within buildings, but the same precautions as regards heating of the coils, distance from woodwork, and guarding must be adopted as in the case of resistances used for motors.

Arc Lamps.

14. Arc lamps must always be guarded by lanterns or netted globes, so as to prevent danger from ascending or descending sparks, and from falling glass or incandescent pieces of carbon. All parts of the lamps which are liable to be handled should be well insulated, and, in addition, an insulator must be inserted between the lamp and its support. Resistances for arc lamps should have a similar double insulation; their coils should be designed so as not to heat above 212° Fahr.; they should be protected by metallic ventilating guards, and should be so placed that no woodwork is within 6 inches of them measured horizontally, or within 2 feet of them measured vertically above them. When arc lamps are supplied from constant potential mains, fuses on both mains are necessary.

Arc lamps in which air can have access to the carbons during burning should on no account be used in places where inflammable vapours or explosive mixtures of dust or gas are liable to be present.

Testing.

Insulation test.

15. The conductors, fittings, and appliances must be tested in the following manner before the current is switched on:—The

whole of the lamps or appliances for utilising the energy having been connected to the conductors, and all fuses being in place, an E.M.F. equal to twice the E.M.F. which will be ordinarily used is to be applied, and the insulation resistance between the whole system and earth must be measured after one minute's electrification. The insulation should then not be less than 10 megohms, divided by the maximum number of amperes required for the lamps and other appliances. The installation may be then set to work, and a second and similar test should be made after an interval of 15 days. In each test, if the insulation of the whole is below standard, the work should be divided up by the departmental switches and tested separately, in order to locate the faulty section.

The value of systematically testing and inspecting apparatus and circuits cannot be too strongly urged as a precaution against fire. Records should be kept of all tests, so that any gradual deterioration of the system may be detected. Cleanliness of all parts of the apparatus and fittings is essential. No repairs or alterations should be made when the current is "on."

Explanation of Table.

Column 1 gives the sizes of the conductors in common use. Cables are shown thus:—19/14, viz., 19 wires of No. 14 Standard wire gauge.

Column 2 gives the maximum current for situations where the external temperature is above 100° Fahr.

The current for any conductor may be calculated from the formula—

$$\text{Log } C = 0{\cdot}775 \log A + 0{\cdot}301,$$
$$\text{or } C = 2\,A^{0{\cdot}775}$$

(where C = current in amperes, A = area in 1,000ths of a sq. in.).

The maximum rise in temperature will be about 10° Fahr. on large sizes.

Column 3 gives the total length in yards of lead and return of each size of conductor causing a drop of 1 volt when transmitting the current shown in column 2.

Column 4 gives the maximum current allowable in any situation. The current for any conductor may be calculated from the formula—

$$\text{Log } C = 0{\cdot}82 \log A + 0{\cdot}415,$$
$$\text{or } C = 2{\cdot}6\,A^{0{\cdot}82}$$

(where C = current in amperes, A = area in 1,000ths of a sq. in.).

The maximum rise in temperature will be about 20° Fahr. on large sizes.

Column 5 gives the total length in yards of lead and return of each size of conductor causing a drop of 1 volt when transmitting the current shown in column 4.

Column 6 gives the minimum thickness of dielectric. This

may be obtained for any conductor by adding 30 mils to 1-10th the diameter of the conductor.

Columns 7 and 8 give the insulation resistances in megohms for 1 mile of cable of classes A and B respectively.

By Order of the Council,

F. H. Webb, Secretary.

Offices of the Institution,
28, Victoria Street, Westminster,
July, 1897.

Table showing Maximum Currents, Thickness of Dielectric, and Insulation Resistance for Copper Conductors Insulated and Laid in Casing or Tubing.

1.	2.	3.	4.	5.	6.	7.	8.
Size, S.W.G.	Maximum Current for High External Temperatures.	Total length in Yards of Lead and Return giving 1 Volt Drop.	Maximum Current Allowable.	Total Length in Yards of Lead and Return giving 1 Volt Drop.	Minimum Thickness of Dielectric in Mils or Thousandths of an Inch.	Minimum Insulation Resistance in Megohms for One Mile of Class A.	Minimum Insulation Resistance in Megohms for One Mile of Class B.
18 or 62/38 or 97/40	3·1	23	4·2	18	35	1,200	300
3/22	3·3	23	4·4	17	36	1,200	300
17 or 130/40	4·0	25	5·4	19	36	1,200	300
3/20	4·8	26	6·6	19	38	1,200	300
16 or 110/38 or 172/40	4·9	27	6·8	19	36	1,200	300
15	5·9	28	8·2	20	37	800	300
7/22	6·2	28	8·7	20	38	800	300
14 or 172/38 or 7/21½	7·0	29	9·8	21	38	800	300
3/18	7·5	30	11·0	20	40	600	300
7/20	9·3	31	13·0	22	41	600	300
7/18	14·0	37	21·0	25	44	600	300
19/20	20·0	39	30·0	26	48	600	300
7/16	23·0	40	34·0	27	49	600	300
19/18	31·0	45	48·0	29	54	600	300
7/14	32·0	45	49·0	29	54	400	300
19/16	49·0	51	77·0	32	62	400	300
19/14	70·0	53	110·0	35	70	400	300
37/16	83·0	59	130·0	37	75	400	300
19/12	100·0	66	170·0	39	82	300	300
37/14	120·0	64	190·0	40	86	300	300
61/15	150·0	67	240·0	42	95	300	300
61/14	170·0	74	290·0	43	102	300	300
37/12	180·0	73	300·0	44	103	300	300
61/12	260·0	82	450·0	47	124	300	300
91/12	350·0	90	620·0	51	144	300	300
91/11	420·6	94	740·0	53	158	300	300

APPENDIX I.

THE OHMMETER (EVERSHED'S PATENT).

THIS instrument is a Service store for measuring the insulation resistance of incandescent light installations.

It is issued with a hand generator capable of furnishing current at 500 volts, and is capable of measuring resistances up to 50 megohms.

It consists of a soft iron needle pivoted on a vertical arbor in jewelled pivots, and swinging horizontally in the field created by two sets of coils approximately at right angles to one another, shown in Plate XXII as TDC or transverse deflecting coil and DC_1 and DC_2 or deflecting coils which are in series and assist each other. The needle is fixed rigidly to and at right angles to the axis of a thin sheet-iron split tube, which is magnetised by the action of the magnetising coils MC_1 and MC_2 in the lower part of the instrument, which for clearness have been shown in the diagram in elevation, the deflecting coils and needle being shown in plan. From the arrangement adopted, it follows that the needle has the same polarity at each end.

The principle of the instrument is as follows:—If it be desired to test an insulation resistance, the ends of the resistance, or line and earth, are connected to the terminals L and E and the generator is connected to the terminals GG. Let us suppose for the moment that the resistance between L and E is infinite; then the only path open to the current from the generator is through the transverse coil TDC, and through the inner magnetising coil MC_1; the needle pivoted at O is magnetised by the action of the magnetising coil, and being free to revolve in the plane of the paper in the diagram, tends to set itself in the direction of the lines of force due to the current round TDC, *i.e.* tends to set itself as shown in the diagram along the short axis of the coil. This circuit is shown in firm lines. The pointer P attached to the needle will now mark infinity on the scale.

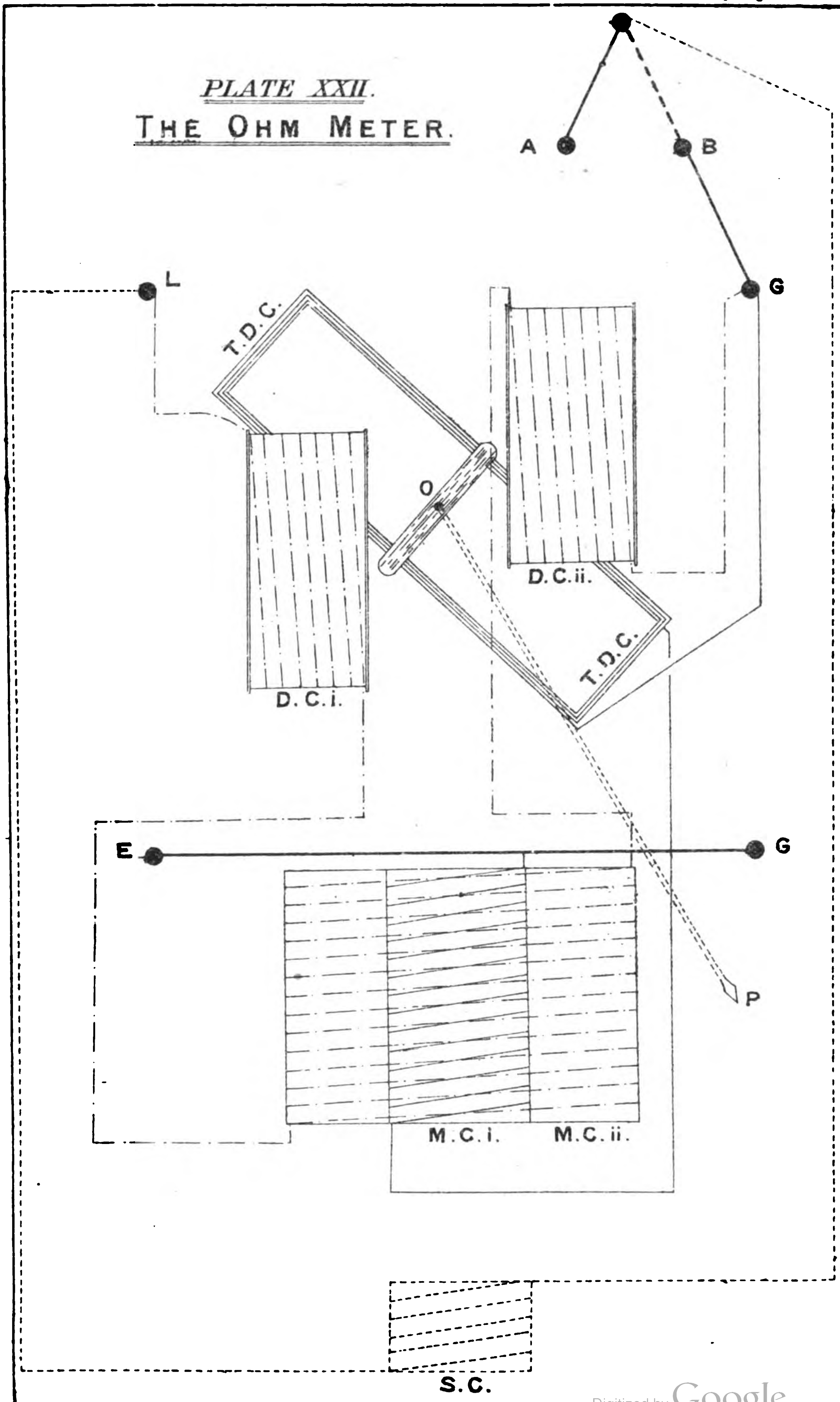
Should, however, the resistance between L and E not be infinite, part of the current from the generator will pass through DC_2 MC_2 and DC_1 *vide* chain dotted lines. (MC_2 is provided in order to keep up the magnetisation of the needle, which would otherwise be weakened, owing to part of the current round MC_1 having now been diverted, and the volts at the generators terminals falling as the load is increased.

Now, the effect of a current passing through DC_1 and DC_2 will be evidently to rotate the needle in a clockwise direction so as to get its ends inside the bobbins of the coils; and how great this effect is will depend upon the amount of current passing.

To face page 216.

PLATE XXII.

THE OHM METER.



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which in its turn depends upon the resistance between L and E. The result of the passage of any current through the coils is to tend to move the pointer to the left until a balanced effect on the needle between the two sets of coils TDC and $DC_1 + DC_2$ is arrived at, when the pointer will indicate on the scale the exact resistance between L and E.

With the switch on A, as shown in the diagram, readings may be taken up to 50 megohms with fair accuracy. For readings below about 5 megohms, it is advisable to place the switch on B. This introduces a shunt SC (*vide* plain dotted lines), which weakens the effect of the coils DC_1 and DC_2 and the observed readings on the scale must now be divided by 10. The coil SC also tends to keep up the magnetism of the needle.

The resistances of the various coils in the instrument are approximately as follows:—

	Ohms.
Magnetising coil, i	71,700
Magnetising coil, ii	45,400
Deflecting coil, i	2,135
Deflecting coil, ii	2,230
Transverse deflecting coil	380
Shunt coil	5,560

The generator is hand driven, geared up about 15 to 1 and is of the magneto type, a toothed armature revolving between two soft iron pole pieces magnetised by four steel permanent magnets.

The resistance of the armature is approximately = 11,000 ohms.

APPENDIX II.

CONSTANTS OF GENERATORS.

Machine.	Type of—		Number of—			Speed.	P.D. at Machine Terminals.	Current.	Resistance in Ohms.			Weight.	Remarks.
	Machine.	Armature.	Pole Pieces.	Sets of Brushes.	Sections in Armature	Revolutions per Minute.	Volts	Amperes.	Series Coil.	Armature.	Shunt Coil.	Cwts.	
D_2 Siemens	Series ..	Drum	2	2	56	680	0	30	0·32	0·32	...	4	
Do. converted ...	Compound	Drum	2	2	56	700		30	0·16	0·32	38·0	4	
D Gramme	Series ...	Ring	2	2×2	56×2	500	60	80	0·19	0·13	...	20	Double wound armature and two commutators
D_2 Victoria	Compound	Discoidal ring	4	2	60	650	65	150	0·01	0·025	7·0	17	
D_2 Victoria S. Type ...	Compound	Discoidal ring	4	2	60	810	70	180	0·006	0·017	11·0	17	
16 unit, present model	Compound	Drum	2	2	52	650	80	200	0·005	0·015	18·0	$38\frac{1}{4}$	

APPENDIX III

FUSES OR CUT OUTS.

The following table may be useful as showing at what current tin wire of various gauges will fuse:—

S.W.G.	Current to Fuse.
	Amperes.
14	37·2
16	26·6
18	17·3
20	11·2
22	7·69
24	5·36
26	3·97
28	2·96
30	2·27
32	1·84

In the above figures the wires are supposed to be so long that the cooling effect of the terminals may be neglected. If the wires be very short, of course the current will need to be larger to melt the wire.

APPENDIX IV.

TABLES OF STANDARD SIZES OF COPPER CONDUCTORS.

Number of Wires in Strand.	Standard Gauge of each Wire.	Diameter—				Equivalent to Solid Wire.				Weight of Conductor.		Resistance at 60° Fahr.	
		Of each Single Wire.		Of the Strand.		Diameter.		Area.		Per 1,000 Yards.	Per Kilometre.	Per 1,000 Yards.	Per Kilometre.
		Inches.	mm.	Inches.	mm.	Inches.	mm.	Square Inches.	Square mm.	Lbs.	Kilogrs.	Ohms.	Ohms.
1	22	·028	·711	...	...	·028	·711	·0006	0·397	6·82	3·4	41·200	45·0600
1	21	·032	·813	...	...	·032	·813	·0008	0·518	9·09	4·5	31·550	34·5000
1	20	·036	·914	...	...	·036	·914	·0010	0·656	11·93	5·9	24·920	27·2500
1	19	·040	1·020	...	...	·040	1·020	·0012	0·810	14·77	7·4	20·180	22·0700
1	18	·048	1·220	...	...	·048	1·220	·0018	1·167	21·02	10·0	14·020	15·3300
1	17	·056	1·420	...	...	·056	1·420	·0024	1·588	28·41	14·0	10·300	11·2600
1	16	·064	1·620	...	...	·064	1·620	·0032	2·075	36·93	19·0	7·880	8·6240
1	15	·072	1·830	...	...	·072	1·830	·0040	2·626	47·16	24·0	6·230	6·8160
1	14	·080	2·030	...	...	·080	2·030	·0050	3·242	57·95	29·0	5·050	5·5200
1	13	·092	2·340	...	...	·092	2·340	·0066	4·287	76·70	38·0	3·820	4·1740
1	12	·104	2·640	...	...	·104	2·640	·0085	5·480	98·29	49·0	2·990	3·2660
1	11	·116	2·940	...	...	·116	2·940	·0105	6·774	122·16	61·0	2·400	2·6250
1	10	·128	3·250	...	...	·128	3·250	·0128	8·302	148·86	74·0	1·970	2·1560
1	9	·144	3·650	...	...	·144	3·650	·0162	10·500	188·64	94·0	1·560	1·7030
1	8	·160	4·060	...	...	·160	4·060	·0201	12·970	232·38	116·0	1·260	1·3800

3	25	·020	·508	·042	1·07	·034	·863	·0009	0·585	10·79	5·4	26·580	29·0700
3	23	·024	·609	·051	1·29	·042	1·060	·0014	0·893	15·91	7·9	18·460	20·1900
3	22	·028	·711	·059	1·50	·049	1·240	·0019	1·216	21·59	11·0	13·560	14·8300
7	25	·020	·508	·060	1·54	·053	1·350	·0022	1·423	25·57	12·0	11·370	12·4300
7	23	·024	·609	·072	1·83	·064	1·620	·0032	2·075	36·93	19·0	7·890	8·6300
7	22	·028	·711	·084	2·13	·075	1·900	·0044	2·849	50·57	25·0	5·790	6·3370
7	21½	·030	·762	·090	2·28	·080	2·030	·0050	3·242	57·95	29·0	5·050	5·5250
7	20½	·033	·838	·099	2·51	·088	2·230	·0061	3·923	70·45	35·0	4·170	4·5610
7	20	·036	·914	·108	2·74	·096	2·430	·0072	4·650	83·50	42·0	3·510	3·8350
7	19	·040	1·020	·120	3·04	·107	2·710	·0089	5·770	103·40	52·0	2·842	3·1080
7	18	·048	1·220	·144	3·66	·128	3·250	·0128	8·300	143·20	74·0	1·979	2·1580
7	17	·056	1·420	·168	4·27	·149	3·780	·0174	11·280	202·30	100·0	1·450	1·5850
7	16	·064	1·630	·192	4·88	·171	4·340	·0229	14·730	264·20	132·0	1·110	1·2130
7	15	·072	1·830	·216	5·49	·192	4·870	·0289	18·660	334·60	166·0	·877	·9589
7	14	·080	2·030	·240	6·10	·213	5·410	·0356	22·980	413·10	205·0	·712	·7785
19	20	·036	·914	·180	4·57	·159	4·030	·0198	12·740	228·40	113·0	1·285	1·4040
19	19	·040	1·020	·200	5·08	·176	4·470	·0243	15·720	281·80	140·0	1·040	1·1370
19	18	·048	1·220	·240	6·10	·211	5·350	·0349	22·660	406·20	201·0	·722	·7897
19	17	·056	1·420	·280	7·10	·247	6·270	·0479	30·910	552·80	274·0	·528	·6704
19	16	·064	1·630	·320	8·12	·282	7·160	·0624	40·250	721·60	358·0	·406	·4445
19	15	·072	1·830	·360	9·14	·317	8·050	·0789	50·960	913·60	453·0	·321	·3512
19	14	·080	2·030	·400	10·10	·352	8·940	·0973	62·770	1,127·80	559·0	·260	·2845
19	13	·092	2·340	·460	11·60	·404	10·700	·1282	83·200	1,491·50	740·0	·197	·2151
19	12	·104	2·640	·520	13·20	·458	11·600	·1647	106·300	1,905·70	945·0	·154	·1683
37	16	·064	1·630	·448	11·30	·394	10·000	·1219	78·600	1,410·00	699·0	·208	·2274
37	15	·072	1·830	·504	12·80	·443	11·200	·1541	99·580	1,785·00	855·0	·164	·1797
37	14	·080	2·030	·560	14·20	·493	12·500	·1909	122·900	2,204·00	1,093·0	·133	·1456
37	13	·092	2·340	·644	16·30	·566	14·300	·2516	162·600	2,915·00	1,445·0	·101	·1101
37	12	·104	2·640	·728	18·40	·640	16·200	·3217	207·700	3,724·00	1,847·0	·079	·0861
61	13	·092	2·340	·828	21·00	·728	18·500	·4162	268·700	4,816·00	2,389·0	·061	·0666
61	12	·104	2·640	·936	23·70	·823	20·900	·5319	333·400	6,154·00	3,052·0	·048	·0521

APPENDIX V.

TREATMENT TO BE FOLLOWED IN CASE OF A DANGEROUS SHOCK.

It is not likely, with the pressures in use in the Service, that this contingency will arise; it is just conceivable, however, that by the accidental breaking of the shunt coil of a dynamo, or similar circumstance, a man might be rendered unconscious.

In such an event, the proper course to pursue is to treat the patient as if apparently drowned, and with this in view, the instructions on this subject issued by the Royal Lifeboat Institution are appended in full.*

Directions for Restoring the Apparently Drowned.

The leading principles of the following Directions for the Restoration of the Apparently Dead from Drowning are founded on those of the late Dr. Marshall Hall, combined with those of Dr. H. R. Silvester, and are the result of extensive inquiries which were made by the Royal National Lifeboat Institution in 1863–4 amongst Medical Men, Medical Bodies, and Coroners throughout the United Kingdom. These directions have been extensively circulated by the Institution throughout the United Kingdom and in the Colonies. They are also in use in Her Majesty's Fleet; in the Coast-guard Service; at all the Stations of the British Army at home and abroad; in the Light Houses and Vessels of the Corporation of the Trinity House; the Metropolitan and Provincial Police Forces; the Metropolitan School Board Schools; and the St. John Ambulance Association.

I.

Send immediately for medical assistance, blankets, and dry clothing, but proceed to treat the patient instantly on the spot, in the open air, with the face downward, whether on shore or afloat; exposing the face, neck, and chest to the wind, except in severe weather, and removing all tight clothing from the neck and chest, especially the braces.

The points to be aimed at are—first, and immediately, the restoration of breathing; and secondly, after breathing is restored, the promotion of warmth and circulation.

The efforts to restore breathing must be commenced immediately and energetically, and persevered in for one or two hours, or until a medical man has pronounced that life is extinct. Efforts to

* These instructions are printed by permission of the Royal Lifeboat Institution.

promote warmth and circulation, beyond removing the wet clothes and drying the skin, must not be made until the first appearance of natural breathing; for if circulation of the blood be induced before breathing has recommenced, the restoration to life will be endangered.

II.—To Restore Breathing.

To Clear the Throat.—Place the patient on the floor or ground with the face downwards, and one of the arms under the forehead, in which position all fluids will more readily escape by the mouth, and the tongue itself will fall forward, leaving the entrance into the windpipe free. Assist this operation by wiping and cleansing the mouth.

If satisfactory breathing commences, use the treatment described below to promote warmth. If there be only slight breathing—or no breathing—or if the breathing fails, then—

To Excite Breathing—Turn the patient well and instantly on the side, supporting the head, and—

1.—INSPIRATION.

Fig. 127.

Excite the nostrils with snuff, hartshorn, and smelling salts, or tickle the throat with a feather, &c., if they are at hand. Rub the chest and face warm, and dash cold water, or cold and hot water alternately, on them. If there be no success, lose not a moment, but instantly—

To Imitate Breathing—Replace the patient on the face, raising and supporting the chest well on a folded coat or other article of dress.

Turn the body very gently on the side and a little beyond, and then briskly on the face, back again, repeating these measures cautiously, efficiently, and perseveringly, about fifteen times in the minute, or once every four or five seconds, occasionally varying the side. (By placing the patient on the chest, the weight of the body forces the air out; when turned on the side, this pressure is removed, and air enters the chest.)

2.—EXPIRATION.

Fig. 128.

The foregoing two Illustrations show the position of the Body during the employment of Dr. Marshall Hall's Method of inducing Respiration.

On each occasion that the body is replaced on the face, make uniform but efficient pressure with brisk movement, on the back between and below the shoulder-blades or bones on each side, removing the pressure immediately before turning the body on the side.

During the whole of the operations let one person attend solely to the movements of the head and of the arm placed under it. (The first measure increases the expiration—the second commences inspiration.)

The result is respiration or natural breathing;—and if not too late, life.

Whilst the above operations are being proceeded with, dry the hands and feet, and as soon as dry clothing or blankets can be procured, strip the body, and cover or gradually reclothe it, but taking care not to interfere with the efforts to restore breathing.

III.

Should these efforts not prove successful in the course of from two to five minutes, proceed to imitate breathing by Dr. Silvester's method, as follows:—

Place the patient on the back on a flat surface, inclined a little upwards from the feet; raise and support the head and shoulders on a small firm cushion or folded article of dress placed under the shoulder-blades.

Draw forward the patient's tongue, and keep it projecting beyond the lips: an elastic band over the tongue and under the chin will answer this purpose, or a piece of string or tape may be tied round them, or by raising the lower jaw, the teeth may be made to retain the tongue in that position. Remove all tight clothing from about the neck and chest, especially the braces.

To Imitate the Movements of Breathing.—Standing at the patient's head, grasp the arms just above the elbows, and draw the arms gently and steadily upwards above the head, and keep

1.—INSPIRATION.

Fig. 129.

them stretched upwards for two seconds. (By this means air is drawn into the lungs.) Then turn down the patient's arms, and press them gently and firmly for two seconds against the sides of the chest. (By this means air is pressed out of the lungs.)

Repeat these measures alternately, deliberately, and perseveringly, about fifteen times in a minute, until a spontaneous effort to respire is perceived, immediately upon which cease to imitate the movements of breathing, and proceed to induce circulation and warmth.

2.—EXPIRATION.

Fig. 130.

The foregoing two Illustrations show the position of the Body during the employment of Dr. Silvester's Method of inducing Respiration.

IV.—Treatment after Natural Breathing has been Restored.

To Promote Warmth and Circulation.—Commence rubbing the limbs upwards, with firm grasping pressure and energy, using handkerchiefs, flannels, &c. (By this measure the blood is propelled along the veins towards the heart.)

The friction must be continued under the blanket or over the dry clothing.

Promote the warmth of the body by the application of hot flannels, bottles, or bladders of hot water, heated bricks, &c., to the pit of the stomach, the arm-pits, between the thighs, and to the soles of the feet.

If the patient has been carried to a house after respiration has been restored, be careful to let the air play freely about the room.

On the restoration of life, a teaspoonful of warm water should be given; and then, if the power of swallowing have returned, small quantities of wine, warm brandy-and-water, or coffee should be administered. The patient should be kept in bed, and a disposition to sleep encouraged.

General Observations.

The above treatment should be persevered in for some hours, as it is an erroneous opinion that persons are irrecoverable because life does not soon make its appearance, persons having been restored after persevering for many hours.

Appearances which generally Accompany Death.

Breathing and the heart's action cease entirely; the eyelids are generally half closed; the pupils dilated; the tongue approaches to the under edges of the lips, and these, as well as the nostrils, are covered with a frothy mucus. Coldness and pallor of surface increase.

Cautions.

Prevent unnecessary crowding of persons round the body, especially if in an apartment.

Avoid rough usage, and do not allow the body to remain on the back unless the tongue is secured.

Under no circumstances hold the body up by the feet.

On no account place the body in a warm bath unless under medical direction, and even then it should only be employed as a momentary excitant.

APPENDIX VI.

TREATMENT TO BE FOLLOWED IN CASE OF INJURY BY ACIDS.

I.—Immediate Treatment of Wounds of the Skin Caused by Acids.

EXCLUDE the air by means of lint steeped in sweet oil, arranged so as to cover the affected part. Then place a layer of cotton wool over the lint, and secure by a bandage.

II.—Immediate Treatment of Wounds of the Eye Caused by Acids.

Wash out the whole eye carefully with a strong alkaline solution, then apply two cocaine discs and cover up the eye with a handkerchief or bandage.

To apply the discs, pull down the lower eyelid and place the discs on it by means of a small camel's hair brush, then allow the lid to resume its normal position. The man should be sent to hospital as quickly as possible in a cab.

If the shock from severe pain is great, the patient should lie down and stimulants may be given.

Franco-German War, 1870-71—*continued.*

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